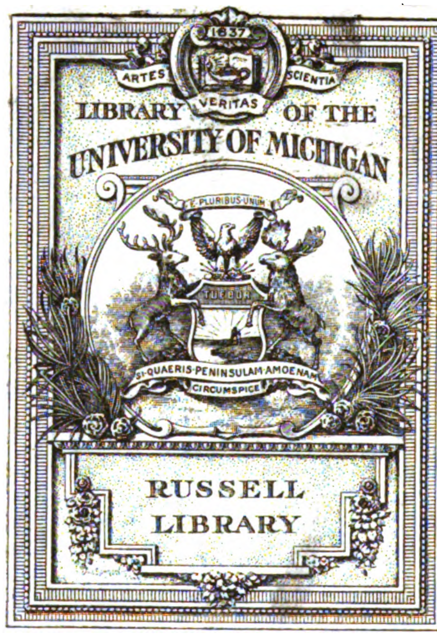
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BULLETIN

OF THE

GEOLOGICAL SOCIETY

OF

AMERICA

VOL. 9.

JOSEPH STANLEY-BROWN, *Editor.*

ROCHESTER
PUBLISHED BY THE SOCIETY
1898

COUNCIL FOR 1898

PRINTERS

JUDD & DETWEILER, WASHINGTON, D. C.

ENGRAVERS

THE MAURICE JOYCE ENGRAVING CO., WASHINGTON, D. C.

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(29 plates; 49 figures.)

PUBLICATIONS OF THE GEOLOGICAL SOCIETY OF AMERICA

Regular Publications

The Society issues a single serial octavo publication entitled Bulletin of the Geological Society of America. This serial is made up of *proceedings* and *memoirs*, the former embracing the records of meetings, with abstracts and short papers, list of Fellows, etcetera, and the latter embracing larger papers accepted for publication. The matter is issued as rapidly as practicable, in covered brochures, which are at once distributed to Fellows and to such exchanges and subscribers as desire the brochure form of distribution. The brochures are arranged for binding in annual volumes, which are elaborately indexed. To this date eight volumes have been published.

The Bulletin is sold to Fellows of the Society and to the public either in separate brochures or in complete (unbound) volumes. The *prices* are as follows: To libraries and to persons residing outside of North America, five dollars ($5.00) per volume; to persons in North America, not Fellows of the Society, ten dollars ($10.00) per volume (the same amount as the annual dues of the Fellows); to Fellows of the Society, a variable amount, depending on the cost of publication. These prices cover cost of transmission to all parts of the globe. No reduction is made to dealers. Subscribers should specify whether they desire the brochures or the completed volume. Orders should be addressed to the Secretary, and drafts and money orders made payable to the *Secretary of the Geological Society of America*, Rochester, New York.

Description of the published Volumes

Volumes.	Pages.	Plates.	Figures.	Price to Fellows.
Vol. 1, 1889	593 + xii	13	51	$4.50
Vol. 2, 1890	662 + xiv	23	63	4.50
Vol. 3, 1891	541 + xi	17	72	4.00
Vol. 4, 1892	458 + xi	10	55	3.50
Vol. 5, 1893	665 + xii	21	43	4.00
Vol. 6, 1894	528 + x	27	40	4.00
Vol. 7, 1895	558 + x	24	61	4.00
Vol. 8, 1896	446 + x	51	29	4.00
Vol. 9, 1897	460 + x	29	49	4.00

Brochures of Volume 9

Brochures.	Pages.	Plates.	Figures.	Price to Fellows.	Price to the Public.
Proceedings of the Ninth Summer Meeting, held at Detroit, Michigan, August 10, 1897. H. L. Fairchild, *Secretary*	1–12	....	....	$0.15	$0.30
Great changes of level in Mexico and the interoceanic connections. J. W. Spencer	13–34	1–5	1–6	.45	.90
Clay-veins vertically intersecting Coal Measures. W. S. Gresley	35–58	....	1–27	.30	.60

Irregular Publications

In the interest of exact bibliography, the Society takes cognizance of all publications issued wholly or in part under its auspices. Each author of a Memoir receives 30 copies without cost, and is authorized to order any additional number at a slight advance on cost of paper and presswork; and these separate brochures are identical with those of the editions issued and distributed by the Society. Contributors to the Proceedings are also authorized to order any number of separate copies of their papers at a slight advance on cost of paper and presswork; but such separates are bibliographically distinct from the brochures issued by the Society.

The following separates of parts of volume 9 have been issued:

Editions uniform with the Brochures of the Society

Pages	13– 34, plates 1–5;	130 copies,	December	31,	1897.
"	35– 58,	130 "	January	18,	1898.
"	59– 84,	200 "	"	24,	"
"	85–100,	80 "	"	24,	"
"	101–110,	30 "	"	25,	"

Pages	111–162, plates 6–10;	100 copies.	February	8,	1898.
"	163–172, plate 11;	330 "	"	10,	"
"	173–182, plates 12–14;	100 "	"	17,	"
"	183–210, plate 15;	30 "	"	19,	"
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"	269–328, plate 19;	300 "	May	19,	"
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"	343–368, plates 24–26;	175 "	June	21,	"
"	369–390,	200 "	June	22,	"

SPECIAL EDITIONS*

Pages	2– 6,†	50 copies.		December	30,	1897.
"	6– 9,	80 "		"	30,	"
"	10– 11,	30 "		"	30,	"
"	10– 11,	30 "		January	1,	1898.
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"	vii–viii,	430 "		December	1,	"

* Bearing the imprint [" From Bull. Geol. Soc. Am., vol. 9, 1897 "].
† Fractional pages are sometimes included.

CORRECTIONS AND INSERTIONS

All contributors to volume 9 have been invited to send in corrections and insertions to be made in their compositions, and the volume has been scanned with some care by the Editor. The following are such corrections and insertions as are deemed worthy of attention:

Page 195, line 5 from bottom; *for* "plate 15, page 183," *read* figure 2, page 206
" 207, " 2 " " ; *for* "shores" *read* noses
" 243, " 17 " " ; *for* "orthoclase-syenite-porphyries" *read* orthoclase-porphyries
" 249, " 11 " top; *for* "Tousenäs" *read* Tonsenäs
" 253, " 13 " " ; *for* "Werd" *read* Weed
" 256, page heading; *for* syenite-porphery" *read* syenite-porphyry
" 269, line 3 from top; *for* "(Presented before the Society December 29, 1897)" *read* (Accepted by the Publication Committee April 20, 1898). The correct statement is made on page 427
" 419, " 16 " " ; *for* "1432" *read* 1423
" 419, " 6 " bottom; *for* "1431" *read* 1432
" 420, " 1 " top; *for* "Tialpam" *read* Tlalpam
" 423, " 5 " " ; *for* "Nebraska" *read* South Dakota
" 425, " 11 " bottom; "1551" and the descriptive text should immediately follow 1550 and thus the photographs donated will be credited to Whitman Cross, who presented them to the Society

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 9, PP. 1-12 DECEMBER 30, 1897

PROCEEDINGS OF THE NINTH SUMMER MEETING, HELD AT DETROIT, MICHIGAN, AUGUST 10, 1897

HERMAN LE ROY FAIRCHILD, *Secretary*

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SESSION OF TUESDAY, AUGUST 10

The Society was called to order at 10.45 o'clock a m (local time) in room 211 of the Central High School building, the President, Professor Edward Orton, in the chair. By a mutual understanding between the Society and the American Association for the Advancement of Science, the Geological Section (Section E) of the Association had temporarily suspended its sessions and yielded the use of its room and time to this meeting of the Society.

ELECTION OF FELLOWS

The Secretary announced that the nine candidates for fellowship had received a nearly unanimous vote of the ballots transmitted, and that they were elected, as follows:

Fellows Elected

RICHARD ELWOOD DODGE, A. B., A. M., Teachers' College, West 120th street, New York, N. Y. Professor of Geography in the Teachers' College.

CHARLES REDWAY DRYER, A. B., M. A., M. D., Terre Haute, Indiana. Professor of Geography, Indiana State Normal School.

WILBUR C. KNIGHT, B. S., A. M., Laramie, Wyoming. Professor of Mining and Geology in the University of Wyoming.

CYRUS FLETCHER MARBUT, A. B., A. M., State University, Columbia, Missouri. Instructor in Geology, and Assistant on Missouri Geological Survey.

HENRY FAIRCHILD OSBORN, Sc. D., Columbia University, New York, N. Y. Professor of Zoology in Columbia University, and Curator in Vertebrate Paleontology, American Museum of Natural History.

EDMUND CHASE QUEREAU, Ph. B., Ph. D., Syracuse, New York. Professor of Geology, Syracuse University.

GEORGE OTIS SMITH, A. B., Ph. D., Washington, D. C. Assistant Geologist, U. S. Geological Survey.

WILLIAM GEORGE TIGHT, B. S., M. S., Granville, Ohio. Professor of Geology and Biology, Denison University. Engaged in glacial geology.

JOHAN AUGUST UDDEN, A. B., A. M., Rock Island, Illinois. Professor of Geology and Natural History in Augustana College.

After some announcements the President declared the reading of papers in order, under the customary rules. The first paper was—

GRANITE MOUNTAIN AREA OF BURNET COUNTY, TEXAS

BY FREDERIC W. SIMONDS

The second paper was entitled:

STRATIGRAPHY AND STRUCTURE OF THE PUGET GROUP, WASHINGTON

BY BAILEY WILLIS

[*Abstract*]

Contents

INTRODUCTION.

The article of which the following pages form an abstract is the result of field work conducted in the years 1881 to 1884 for the Northern Transcontinental Survey, and in 1895 and 1896 for the U. S. Geological Survey. The district particularly described is that which lies east of the southern portion of Puget sound, extending from the vicinity of Seattle to the foothills of mount Rainier. Most of the localities are comprised within the area of the Tacoma quadrangle of the atlas of the United States.

PHYSIOGRAPHY

The water bodies of Puget sound occupy deep and steep-sided channels in an elevated expanse of gravelly deposits, which is further divided by valleys that were formerly arms of the sound, but which are now filled with alluvium. The escarpments of the gravelly plateaus rise from 200 to 300 feet above the waters of the Sound and the alluvial plains of its former branches. The surfaces of the plateaus present a great variety of smooth and hummocky levels, supporting occasional rounded hills a hundred feet or more in height. All the aspects of the district are characteristic of forms modeled by extensive glaciers, and the individual features developed either on stagnant ice-sheets or in front of glaciers as morainic ridges or beneath ice of whose lower surface they present the casts.

In the vicinity of the Sound these gravel deposits are deep, extending below sea-level probably several hundred feet, and even at distances of 20 to 30 miles eastward along the foothills of the Cascade range covering the older rocks locally to depths from 300 to 400 feet. They thus determine the topographic aspects of a wide area, almost obliterating the configuration of the solid rock surface upon which they rest.

From the bluffs about the Sound the plateaus rise toward the mountains by terraces, which are often disposed irregularly with reference to existing streams, but in a general way extend above the higher tracts between the rivers. Within these higher areas the deposit of gravel is thin or locally wanting above the older rocks. The canyons cut by the principal rivers flowing from the Cascades and mount Rainier also expose the underlying strata, and they may be seen in occasional isolated outcrops in the gravelly expanse nearer the sound. The topographic aspects are not markedly influenced by these outcrops, over which, as over the plateaus, extends the prevailing forest.

The gravels occur at considerable heights on the Cascades, but their general surface probably does not extend to much more than 1,000 feet above sea. From it the mountains rise up boldly, sometimes with precipitous fronts. Between these bold foothills on the east and the all-concealing gravels on the west is the zone, 10 to 20 miles wide, of terraces and transverse canyons throughout which the coal-bearing strata may be traced. It is worthy of note that the known productive coal fields all lie in the lower basin of Puget sound and not upon the higher western slopes of the Cascade range.

Valleys, canyons, and hills older than the present ones lie buried beneath the gravel deposits. They are so concealed that no clear conception can be formed of their distribution, but their relatively bold character is indicated by a few facts. In the vicinity of Renton, and between that town and Seattle, sharply defined hills of hard rock rise like islands from the alluvium of the Duwamish valley. The former canyon, now filled almost to the summits of buttes along its course, is inferred to have been deep and steep-sided. At Burnett, 20 miles from tidewater and 335 feet above it, a gangway driven on a coal vein 200 feet below the outcrops passed into a channel filled with gravel and tree roots. The slope from the nearest outcrop to the point where the buried channel was struck descends at an angle of not less than 35 degrees. At Wilkeson a similar buried channel was encountered in a water-level gangway 2,250 feet from the entrance and 250 feet below the level of the overlying gravel terrace. This preglacial topography is of much interest as a phase of the history of the Sound Basin, and it is economically important as a factor which modifies the amount of coal available above any given level. It sometimes introduces difficulties in mining. The topographic surface of the gravel deposits bears no definite relation to that of the Coal Measures.

STRATIGRAPHY

The coal-bearing rocks of the Puget Sound basin have been designated the Puget formation.* They are prevailingly sandstones of variable composition, texture, and color, thinly interbedded, and frequently cross stratified. Their composition varies from that of a typical arkose, consisting of slightly washed granitic minerals, to silicious clays. Beds of concentrated quartz sands or conglomerates have

*C. A. White, Bull. U. S. Geological Survey, no. 51, 1889, pp. 49–63.

not been observed. Carbonaceous materials are generally present as fragments of plants, as vegetal ooze in greater or less proportion to the other constituents, and as distinct coal beds. Carbonate of iron is frequently an integral constituent of the rocks.

In color they are, when fresh, generally bluish gray, shading to brownish black. They weather to buff tints, which are usually dull. The coarser and more massive varieties form beds 20 to 100 feet thick, in which bedding planes are not distinguishable. The finer deposits are thinly laminated and carry abundant leaf impressions, which occasionally interlap with one another so as to form a mass of leaf fragments.

The weathered forms assumed by these rocks rarely present sharp profiles. The more massive beds develop rounded bosses by spheroidal disintegration due to oxidation of the iron carbonate. The thinly bedded strata break down readily, either as a clay mud or in thin scaly fragments, or in angular bits which are externally indurated by a cement of iron oxide.

In many of the sandstones silvery white mica has developed as a secondary mineral, but they exhibit no other indication of metamorphism. The coals, on the contrary, being chemically more sensitive, have undergone metamorphism to a greater or less extent through loss of combined water and concentration of fixed carbon. They vary, therefore, from lignites, whose representative analyses have the range—

	Per cent.
Moisture	8 to 12
Volatile hydrocarbons	35 to 45
Fixed carbon	30 to 45

to bituminous lignites or steam coals, in which the moisture is reduced to 5 per cent or less, and the fixed carbon ranges from 40 to 50 per cent, or to bituminous coking coals, which are fairly represented by the figures:

	Per cent.
Moisture	1 to 3
Volatile hydrocarbons	25 to 35
Fixed carbon	50 to 60

The variations from lignite to bituminous coking coal are of regional extent—that is to say, where lignites are found they may be expected to maintain a uniform composition over a relatively wide area, and bituminous varieties are equally constant in their character within the fields in which they occur. There are, however, occurrences of more condensed coals, ranging into anthracite, which are, so far as is definitely known, of local distribution only.

The cause of variation in quality among these coals may be sought in pressure and movement which they have suffered. The lignites retain the compact structure originally assumed by the peaty deposit under the load of overlying strata. Their beds have been tilted, but internally not much disturbed. They have thereore undergone comparatively moderate chemical change. The Green River steam coals have assumed a more or less cubical structure, due to shearing under pressures which caused movement within the vein. The resulting chemical effect was to expel 5 to 8 per cent of water. Beyond the area of this mechanical influence the coal changes into lignite by transition within a single bed. The coking coals of the Wilkeson field and those of the extreme eastern portion of the Green River field have been rolled out between their walls and crushed. Their softness and their concentrated condition have resulted from this mechanical disturbance. The further transformation of the coal to anthracite and coke occurs in the vicinity of igneous rocks, to whose influence it is wholly due.

The stratigraphic relations of the Puget series are not determinable within the area under discussion, since the strata nowhere come in contact with older sedimentary rocks. Sixty miles northward, on the Skagit river, is a contact between similar coal-bearing strata and older metamorphic schists, described in an earlier report* as possibly a surface of deposition or of faulting. Examination of this locality in 1895 led to the discovery of small pebbles of the schist forming a basal conglomerate in the sandstone beds next the contact, which was therefore a surface of deposition during a transgression. Fossils found in limestone under the schists are stems of crinoids of Carboniferous or Triassic age, whereas the coal-bearing sandstones of this locality are assigned by Knowlton to the Eocene on the evidence of numerous leaf impressions.

The age of the Puget formation has been in doubt because of the obscurity of stratigraphic relations, the general absence of marine fauna, and the indeterminate character of the flora. Collections made for Newberry prior to 1884 represented various stratigraphic horizons which were not distinguished. Most of the species were new. Newberry correlated the plants with the Laramie (Cretaceous) flora, and the series has been dated late Cretaceous or early Eocene. A more definite correlation with the Tejon formation of California has been suggested by C. A. White.

The latest evidence on this still debatable question is that of collections made in 1895 and 1896 from definitely determined stratigraphic horizons on Green river, above Burnett on South Prairie creek, and on Carbon river near Carbonado. A preliminary examination of the fossil plants enables Knowlton to report that the lower beds of the series are Eocene, whereas the upper beds may be of Miocene age. The floras from horizons several thousand feet apart in stratigraphic range are so distinct as to afford means of correlating separate strata of the Puget formation. Further collections and detailed studies must be made before we can determine how closely coal beds may be identified by their fossil plants and to what extent the fossils will aid in working out the complex, obscure relations of distinct parts of the coal fields.

Most prominent among the rocks associated with the Puget group are eruptives of Tertiary or later age. They occur as dikes and flows in various forms of intruded and extruded igneous rocks.

Thus the Puget series is related to four other groups of rocks, which may be named in order of their age, as follows: (1) Metamorphic schists and limestones of Carboniferous or Juratrias date, upon which the Eocene strata were deposited unconformably, at least in the Skagit district; (2) the marine Miocene, or Tejon, with which the Puget series is stratigraphically continuous; (3) the Tertiary eruptives, which are younger than the Puget group, and date down almost to the present time; (4) the Glacial gravel deposits of Pleistocene age.

The measured sections of the Puget series exhibit total thicknesses of 5,800 feet on Green river, 5,500 feet on South Prairie creek, and 5,480 feet in Carbon River canyon. None of these measures is complete. In each instance the lowest stratum is of the Eocene outcropping on an anticline, and the highest is the limit of exposure where the rocks pass under later formations. These sections probably overlap, and there are also higher beds exposed on South Prairie creek above the limit of

* Reports of Tenth Census, vol. xv, p. 760.

the measured sections. These considerations justify the inference that the thickness of the Puget series may probably be 9,000 feet or more.

Structure

The strata of the Puget series were deposited upon the slowly subsiding bottom of the geosyncline between the axes of the present Cascade and Olympic ranges. As strata of similar composition and age are involved in the mass of the Cascade range, and probably also of the Olympics, the uplift of these mountains was to a greater or less extent accomplished after the Puget epoch. From a section observed immediately east of Renton, in which the highest strata of the Puget formation are in overthrust contact with conglomerates derived from the Puget rocks, it is inferred that the effort of compression took place in Miocene time. As a result of this effort the Puget strata were more or less extensively folded, a process to which they readily yielded in consequence of the frequent interbedding of soft coal beds. The resulting folds differ in character in the several productive districts, being in the northern or Gilman field simply monoclinal; in the Green River field broadly flexed, and in the Wilkeson field closely appressed with extensive overthrust faults. The details of these structures are further complicated by normal faulting of later date and the intrusion of the igneous rocks of post-Miocene age.

In general the axes of these folds trend north and south, parallel to the axis of the antecedent geosyncline, but there are evidences in local structures which show that the forces of compression were exerted also at right angles to the greater pressure. In general terms, the structure may be described as that of the Appalachian type modified by the local peculiarities of stratigraphy which give it the specific characteristics of the anthracite coal fields.

The detailed evidence on which these generalizations are based will be presented in the descriptions and maps in the article in the Eighteenth Annual Report of the United States Geological Survey.

Remarks upon the matter of Mr Willis' paper were made by E. W. Claypole.

The paper will be printed in full in the Eighteenth Annual Report of the United States Geological Survey.

The next paper was read by Mr Frank Leverett in the absence of the author.

LOESS AS A LAND DEPOSIT

BY J. A. UDDEN

Contents

Objections to Aqueous Hypothesis

A study of the work of the wind as a geological agent leads me to discuss the bearing this study appears to have on the deposition of the American loess. This

I am led to do since serious objections to the hypothesis of aqueous deposition are being urged. It should be understood that some aqueous deposition is recognized to be necessary. I only wish to show that it fails to cover the whole series of phenomena, and that the wind has been very important and perhaps more potent and far-reaching in influence than water deposition.

It is scarcely necessary to speak of the objections to aqueous deposition based upon topographic relations of the loess. As is well known, this deposit not only borders valleys, but blankets interfluvial tracts as well, often resting on an eroded surface like a mantle of snow, being found on the highest as well as the lowest parts of the previously eroded tracts. It is not rare to find it occurring at elevations differing several hundred feet within a distance of but a few miles. Another objection to aqueous deposition, based upon absence of shorelines, has recently been made. The occurrence of terrestrial shells in the loess I also merely mention as a feature out of harmony with the theory of aqueous deposition, especially of deposition in a large body of water.

Adequacy of Wind as shown in the Mississippi Valley

That the wind is adequate to produce such a deposit seems to be certain from the fact that materials of the same kind are constantly carried by the air. The question then also arises whether the conditions in the Mississippi valley are or may have been such that wind sediments may have accumulated in the territory now covered by the loess. I wish to call your attention to these points. They may be very briefly stated as follows:

1. *The universal presence of mineral dust in the atmosphere, and its constant settling, necessitates its accumulation in places where erosion is at a standstill or where it does not exceed the rate of atmospheric sedimentation.*

It seems possible that the conditions prevailing at the present time in some places in the Mississippi valley permit a secular accumulation of atmospheric dust. Observations which I have made in this direction indicate, however, that the quantity of atmospheric sediments now laid down is too small to give support to the view that there is any general accumulation of this kind going on over the loess region at the present time; but the same observations also indicate that the quantity of dust carried in the air is subject to extreme variations with rather moderate changes in meteoric conditions. The atmospheric sedimentation of the present time is hence no certain quantitative index for the past, and it seems quite possible that conditions may at some time have been more favorable to its effectiveness than they seem to be at present.

2. *Erosion of the flat loess-covered uplands is at the present time exceedingly slow as compared with the average rate of denudation of the whole Mississippi valley.*

This is a circumstance of importance in considering the possibility of an accumulation of wind sediments, for if extreme differences occur in the rate of surface denudation, it follows that by a very small addition of sediments in one place, where erosion is least rapid, the land may be built up, while it is being levelled down in other places where surface erosion is more rapid.

From the topography of the Mississippi valley it is quite evident that denudation progresses at a very unequal rate for different parts of the land surface. Owing to the greater slope of the land in the peripheral regions of the valley, erosion there is much more rapid than in the central region. On the west slope this difference is at present so great that there is a zone running north and south over the plains, where the western tributaries are leaving a part of their load and building up the land. Again, the comparatively slow denudation east of this zone is itself distributed unequally, being largely confined to the drainage channels and only to a very small extent, as sheet erosion, affecting the flat surface of uplands away from creeks and gullies. The lateral slopes of the smallest as well as of the largest drainage channels in the loess region soon merge into the nearly horizontal upland plain. Erosion decreases with the slope and practically ceases with it. Rain water on a level surface appears to soak into the ground as rapidly as it falls, even in the heaviest rains. This is especially the case where the surface is covered by vegetation. By far the greater part of the land area in the region of the loess consists of such flat land. It is believed that the greater part of the sediments of the Mississippi are taken from its own bed and bluffs and from the beds and immediate slopes of its tributaries, large and small. These constitute mere narrow belts, which dissect the much more extensive plains, and they occupy only a small part of the entire land surface. The greater part of the land denudation in the central region of the Mississippi valley is hence confined to a comparatively limited area, from which the greater part of the river's load is taken. The removal of only a small quantity of materials from the much more extensive level uplands must make their planing down by sheet erosion exceedingly slow. Evidently this rate would be still further reduced if the drainage were more sluggish. It might be so slow as not to equal the secular accumulation of atmospheric dust on the land surface, in which case this would of course accumulate.

Similarity of Composition of Dust and Loess

In their mechanical composition fine wind sediments and loess are largely identical. The bulk of each consists of particles from one-sixteenth to one-sixty-fourth of a millimeter in diameter, with two nearly symmetrically decreasing series of admixtures above and below these sizes. An aqueous deposit, spread over hundreds of miles of a broken topography and reaching a thickness of a hundred feet, could not very well be as uniform in its mechanical composition as the loess is. It would more frequently contain coarser materials. In particular it seems improbable that a water deposit as fine as the loess should be without thin seams of fine silt, such as are generally to be observed in aqueous sediments. These are more or less conspicuously laminated. In a wind sediment, on the other hand, such a sorting and lamination is impossible, owing to the smallness of each sorted load, to the less constancy of the depositing current, and to disturbing agencies which are at work thoroughly mingling successive deposits on the surface of the land.

Other Features sustaining Eolian Hypothesis

There are other features of the loess which appear easy to explain if it be regarded as a terrestrial deposit. One such feature is the relation which has been shown to exist between the border of the Iowan drift and the loess. At the time of the deposition of these two terranes there was a low drainage gradient. The land to the south of the ice was probably a low swampy plain, where surface erosion was nearly at a standstill except along the water-courses, and where, as a consequence, atmospheric dust may have accumulated. Such accumulations may have reached up over the margin of the ice fields and may thus have caused occasional overlapping of the loess on the Iowan till. The gradual transitions from underlying terranes which often merge, as it were, into the base of the loess, would naturally be formed as the conditions for the accumulation of the loess slowly set in. Thus we should expect to find under the loess here and there the oxidized surface of the older till, old soils, forest beds, peat, overwash aprons, dune sand, etcetera. The loess itself ought to be heaviest and coarsest along the larger drainage channels, where the topography has aided in producing local wind eddies and where the rivers have helped to expose materials to wind action. The water of these rivers may have added a part of the material in some places along their courses. This is indicated by occasional stratified phases of the loess in such localities. The multiple age of the loess is also easily accounted for, as with the many climatic changes attendant upon the periods of the ice age, conditions may readily at different times so far have favored the work of the wind as to have allowed the accumulation and the preservation of its sediments.

The paper was discussed by J. W. Spencer, G. F. Wright, E. W. Claypole, G. K. Gilbert, and Frank Leverett.

Following the discussion of Mr Udden's paper, at 12.15 o'clock the Society adjourned for the noon recess.

At 2.15 o'clock p m the Society was again called to order, and in the absence of President Orton Mr G. K. Gilbert was elected temporary chairman.

The following paper was read:

ANALOGY BETWEEN DECLIVITIES OF LAND AND SUBMARINE VALLEYS

BY J. W. SPENCER

At the conclusion of the reading President Orton resumed the chair.

The next paper was by the same author:

GREAT CHANGES OF LEVEL IN MEXICO AND THE INTEROCEANIC CONNECTIONS

BY J. W. SPENCER

The paper is printed in full in this volume.

The two papers by Mr Spencer were discussed together, and remarks were made by E. W. Claypole, W. N. Rice, and G. K. Gilbert.

The following paper was read:

ORIGIN OF THE GORGE OF THE WHIRLPOOL RAPIDS AT NIAGARA

BY F. B. TAYLOR

The paper is printed in full in this volume.

Remarks were made by G. K. Gilbert, J. W. Spencer, G. F. Wright, E. W. Claypole, and the President.

A second paper by the same author was

GLACIAL DRAINAGE OF THE SIMCOE AREA IN ONTARIO

BY F. B. TAYLOR

Remarks were made by J. W. Spencer.

The following paper was then read:

LIMESTONES OF SOUTHEASTERN MICHIGAN, WITH THEIR ASSOCIATED SANDSTONE, SALT, AND GYPSUM

BY W. H. SHERZER

[*Abstract*]

Passing in a northeast and southwest direction across the southeastern corner of Michigan is a low anticline, which crosses Monroe county and enters Wayne county south of Detroit. It is on this anticlinal ridge that most of the natural outcrops and quarries occur in this portion of the state. The oldest rocks exposed belong to the Waterlime division of the Lower Helderberg, and extend downward, as determined by deep borings, into the Salina, which reaches a possible thickness at Detroit of 2,000 feet. The Waterlime beds are exposed in the streams and quarries about Monroe, and southwestward towards Sylvania, Ohio. These beds consist of a drab or brown dolomite, in places brecciated, and characterized by the absence of large corals and fish remains. In general fossils are not abundant, and those that are found are in the form of moulds and casts. Calcium carbonate comprises from 54 to 55 per cent of the rock and magnesium carbonate from 42 to 43 per cent. These rocks are used locally for building, road-work, and lime.

A bed of dolomitic oölite may be traced from Stony Point, on the lake Erie shore, southwestward to near the state line. On Plum creek, south of Monroe, this bed is 2 feet thick. The granules here are well rounded, but southwestward they become in places singularly elongated and almost vermiculate, passing into compact dolomite.

A bed of remarkably pure white sand rock, known by the Ohio survey as the Sylvania sandstone, passes northeastward from Sylvania, crosses the Raisin river near Grape, outcrops at a point seven miles northwest of Monroe, and curves eastward to the south of Gibraltar. This sand rock is of interest because of its economic value in glass manufacture, because of the secondary enlargement of its grains, and because it has been regarded as the equivalent of the Oriskany in this region. In Monroe county its thickness seems to range from 20 to 30 feet, but it thickens and broadens correspondingly as it passes northward. What seems to be the same bed is found at Trenton at a depth of 230 feet; at Wyandotte, 280 feet, and at Detroit at 475 feet, it now having attained a thickness of over 100 feet. That this bed cannot be regarded as the equivalent of the Oriskany is shown by the fact that it is overlain by beds of Waterlime, consisting of a silicious dolomite, a brown sandstone, and a light porous dolomite, exposed at Ottawa lake, Raisinville, Maybee, Flat Rock, Gibraltar, and Grosse Isle. With the exception of a few unidentifiable fragments secured by Dr C. Rominger, the bed has never yielded fossils until during the past season's work of the State survey.

The Waterlime beds are much fissured and broken in places, furnishing numerous localities with underground drainage. Several large and small "sinks" occur in the southwestern part of Monroe county, Ottawa lake being the largest. These fill up in the spring and then are drained into subterranean channels. At three different points live fish are reported to have been pumped from wells, a creditable witness assuring me that he saw three mullet-like forms swimming in a pail, having greatly enlarged pectoral fins and being entirely without eyes.

Calcite and celestite occur in the cavities in the beds at various places, and at Maybee these minerals are associated with native sulphur in considerable quantity.

Above this group of beds lies the Corniferous division of the Upper Helderberg, outcropping and artificially exposed at Dundee and Trenton. Just north of the latter place the Sibley Quarry Company has opened more than 40 acres to a maximum depth of 33 to 35 feet. The main dip of the rocks is west 5 degrees south, and equals 2.5 degrees to 3 degrees. Ten beds of limestone, varying in thickness from 2 to 9 feet, are exposed, and two of chert, 14 and 24 inches respectively. The rock is light colored and remarkably rich in lime carbonate, some samples yielding 98 to 99 per cent. Two drill cores have been taken out, and show that the rock becomes more magnesian as it descends. Fossils are very abundant, particularly corals, bryozoa, brachiopods, gasteropods, and lamellibranchs. Fish teeth and spines are occasionally found. In the lower strata the rocks are well bedded and furnish excellent building stone. The quarry refuse is run through a crusher and converted into road material. Burning produces a strong quality of lime, but the chief use of the purer beds is in the manufacture of soda ash and caustic soda.

At Dundee the same beds are exposed, but are thinner. The rock possesses much the same character as at Trenton, contains the same assemblage of fossils, but is more highly impregnated with oil. These rocks, known by the present State survey as the "Dundee limestone," attain a thickness from 100 to 150 feet. Beneath the city of Detroit deep borings reveal the presence of three valuable veins of rock-salt, struck at depths of about 900, 1,200, and 2,000 feet, the combined thickness of which cannot be far from 500 feet. Toward the south these veins approach the surface and become thinner, while northward they deepen and thicken. The highest of the three veins at Wyandotte gives 50 feet of rock-salt, rapidly thins southward to 8 feet, and probably gives out completely at Monguagon creek, being replaced by gypsum in the wells of Church and Company just north of Trenton. At the latter place the second vein in the most northern well shows 33 feet of salt and none in the most southern well, so that here seems to be the southern limit of the rock-salt along the river, with a possible southwestward extension into Monroe county. At both Wyandotte and Trenton the lowest vein is replaced by gypsum and shale, and the Niagara limestone entered at a depth of from 1,250 to 1,400 feet. In the well of the Eureka Iron and Steel Works at Wyandotte what was believed to be the Trenton was reached at 2,610 feet.

The occurrence of such deposits of solid salt in close association with lime carbonate of as high a grade as that of the Sibley quarry at Trenton is of the greatest economic importance to this section of the state. Within less than a decade ten millions of outside capital, employing thousands of workmen, have been attracted thereby to the banks of the Detroit river.

Remarks upon the paper were made by E. W. Claypole.

The following papers were read by title:

NOTES ON THE GEOLOGY OF THE LOWER PENINSULA OF MICHIGAN

BY ALFRED C. LANE

NOMENCLATURE OF THE CARBONIFEROUS FORMATIONS OF TEXAS

BY ROBERT T. HILL

ICE-TRANSPORTED BOULDERS IN COAL SEAMS

BY EDWARD ORTON

CLAY-VEINS VERTICALLY INTERSECTING COAL MEASURES

BY W. S. GRESLEY

This paper is published in full in this volume.

Upon motion of Mr G. K. Gilbert, the thanks of the Society were voted to the Local Committee and to the Geological Section of the American Association for the Advancement of Science.

The President declared the meeting adjourned.

Register of the Detroit Meeting, 1897

The following Fellows attended the session of the Society:

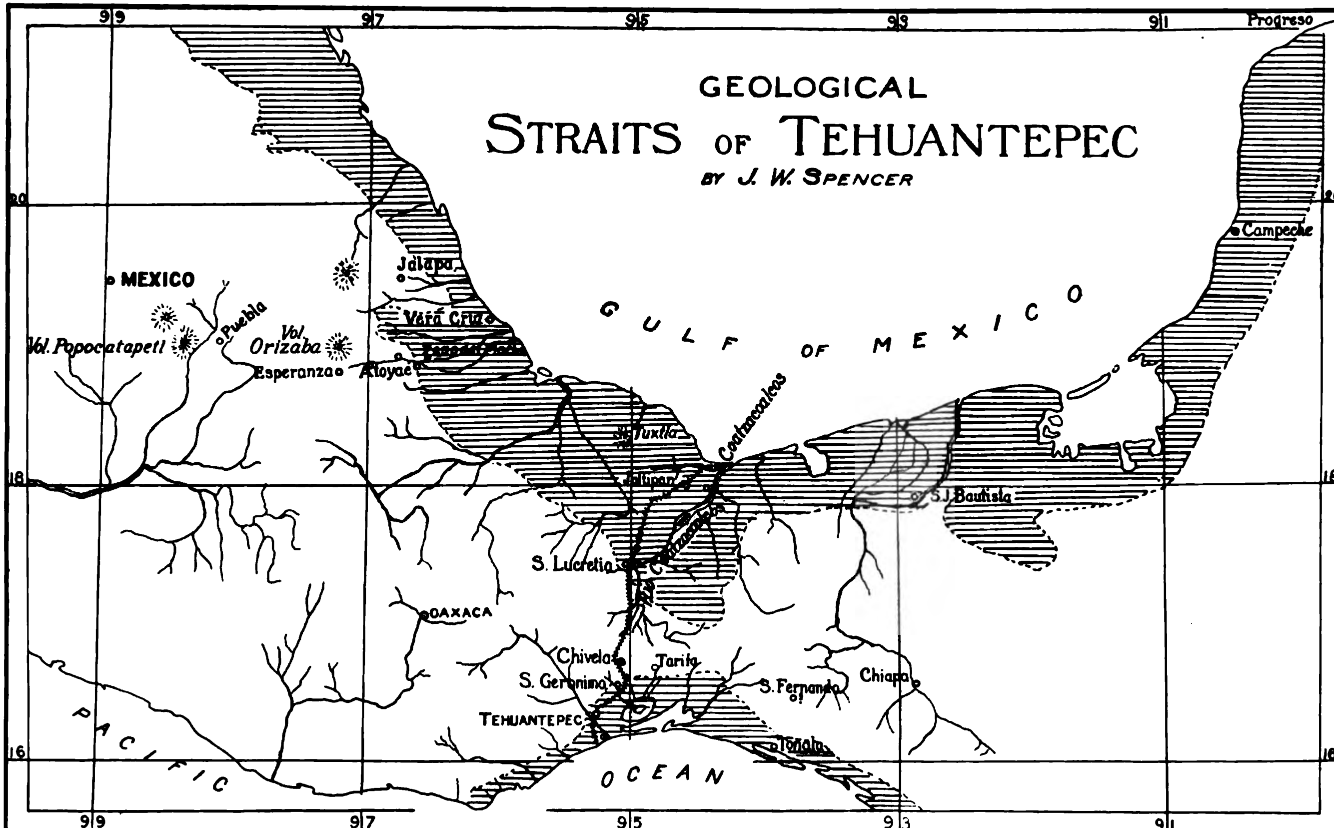
G. H. Ashley.
E. W. Claypole.
H. L. Fairchild.
G. K. Gilbert.
C. H. Gordon.
Frank Leverett.
Edward Orton.
W. N. Rice.
W. H. Sherzer.
F. W. Simonds.
C. H. Smyth, Jr.
J. W. Spencer.
F. B. Taylor.
A. W. Vogdes.
Bailey Willis.
G. F. Wright.

Present at the meeting of the Society, 16.

The following Fellows were in attendance upon the meeting of the American Association for the Advancement of Science:

T. C. Chamberlin.
W J McGee.
R. D. Salisbury.
R. P. Whitfield.
R. S. Woodward.

Total attendance, 21.



GEOLOGICAL STRAITS OF TEHUANTEPEC

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 9, PP. 13-34, PLS. 1-5 DECEMBER 31, 1897

GREAT CHANGES OF LEVEL IN MEXICO AND THE INTER-OCEANIC CONNECTIONS

BY J. W. SPENCER

(*Read before the Society August 10, 1897*)

CONTENTS

INTRODUCTION

In the studies relating to the submarine valleys and plateaus of the West Indian waters which resulted in the contribution entitled "Reconstruction of the Antillean Continent,"* the suggestion that the drainage of the basin of what is now the Gulf of Mexico crossed the Tehuantepec isthmus into the Pacific ocean seemed so probable that the writer visited the region early in 1895, in order to ascertain if the hypothesis was sustained by the physical and geological features of Mexico. The results were so confirmatory that the phenomena will be briefly described here.

Physical Features of Mexico

COASTAL PLAIN OF EASTERN MEXICO

A coastal plain similar to that of the Atlantic states forms a zone in front of the Mexican plateau. It is simply a continuation of that of Texas. On leaving the coast, the inclination of the plain is often uniform and so gradual that the rise is scarcely noticeable. In other localities there is a succession of low steps or surface-washed terraces; or, again, the country may be gently undulating. The landward border of the coastal plain is sharply marked by the escarpments of the plateaus which rise thousands of feet above it. From the Rio Grande the coastal plain extends for 350 miles to above Monterey, where the elevation of 1,700 feet is reached. West of Tampico the plain reaches for a distance of 125 miles from the Gulf, and forms an embayment in the plateau region which rises from 4,000 to 6,000 feet above tide. Along the Interoceanic railway the inner edge of the coastal plain at Colorado station has an elevation of 1,625 feet above the sea. Along the Mexican railway, back of Vera Cruz, its breadth is reduced to 50 miles, with an elevation of 1,560 feet at Paso del Macho.

ATLANTIC COASTAL PLAIN OF THE TEHUANTEPEC ISTHMUS

The isthmus separating the Atlantic and the Pacific waters has a breadth of 140 miles, of which the Atlantic side of 90 miles is characterized at first by low flats with lagoons, and then by rolling plains which gradually rise to an elevation of 325 feet on entering the mountain zone. It is crossed by a large winding river called the Coatzacoalcos, probably 200 miles long, or more than double its direct course. At 60 miles (in direct course, at San Lucretia, at the mouth of the Rio Jaltepec) the surface of the river is about 55 feet above the sea. From 20 to 24 miles (direct course) farther up, the river leaves its canyon section at about 325 feet above the sea. The valley of the Malatenga tributary is less than 4 miles long (direct course), with the canyon section a mile in length, and

* J. W. Spencer: Reconstruction of the Antillean Continent, Bull. Geol. Soc. Am. vol. 6, 1894, pp. 103–140.

PLAINS NEAR PUEBLA, MEXICO

From which rise Popocatapetl and Iztaccihuatl descends about 400 feet from the higher elevations, where there are the remains of baselevels and also terrace plains up to at least 75 feet above the low divide (which is 776 feet above the sea).

PACIFIC COASTAL PLAIN OF THE TEHUANTEPEC ISTHMUS

The Pacific side is distinguished by low plains (with great island studded lagoons) which extend much farther inland than beyond the limits of the isthmus. The plains rise to an elevation of more than 300 feet at the edge of the mountain zone, which is 25 or 30 miles from the sea. Out of the plains occasional island-like bosses, ridges, and *cerros* or isolated dome-like masses rise from a few feet in height to several hundred. These are the remains of an epoch of erosion when the region was reduced to a baselevel of degradation. The floors of the baselevel plains are commonly covered with more recent accumulations of loams and gravels.

HIGH PLATEAUS

Landward of the Gulf coastal plain the escarpments rise rapidly to the elevated plateaus. Thus, back of Vera Cruz, in ascending a valley in a direct line of 40 miles from the foot of the mountain, the floor of the tableland is reached at an elevation of 8,000 feet. Along the Interoceanic railway, a little to the north, the same altitude is reached more quickly.

Southward of Monterey the plains send fingers among the mountain spurs. At a distance of 60 or 70 miles farther south the summit of the plateau is reached at 6.000 feet. After ascending the valley or the steeper slopes of the escarpments the margins of the plateaus are usually very abrupt, but their surfaces are remarkably level plains, out of which rise ranges of hills and interrupted cerros, older mountain chains, and volcanic cones, such as Popocatapetl and Iztaccihuatl, illustrated in plate 2, which reach an elevation of 8,000 or 10,000 feet above the plateau. The extensive plateau thus diversified produces distinctive landscapes. The abrupt margins of the plateaus, whether at less elevations or at 6,000, 8,000, or 10,000 feet above the sea, irrespective of their origin, are incised with canyons often of considerable depth, although not of great length.

MOUNTAIN REGION OF THE TEHUANTEPEC ISTHMUS

This zone is reduced to the remarkably narrow width of only 25 miles, bounded by the two coastal plains. The high plateau region of Mexico, with the mountains rising to an elevation of from 6,000 to 10,000 feet or more, is here broken down for a distance of 60 or 80 miles, so that the higher points do not exceed 4,000 feet, and for a distance of perhaps over 25 miles the ridges are not more than 2,000 feet in height, with baselevels among them. The divide is from 900 to 1,000 feet above sealevel between the higher portals, one of which is shown in plate 3, figure 2, and this is further reduced by channels at 776 and 820 feet above the sea (see plate 3, figure 2). There are the remains of a lower baselevel at 600 feet on the Pacific side and extensive baselevel plains from 800 to less than 700 feet on the Gulf side. The summit of the divide is an old baselevel of earthy sandstones, molded by the rains into a series of hummocks, as shown in plate 3, first illustrated by Mr J. J. Mitchell at a similar pass a dozen miles away.* Interrupted ridges of limestone rise several hundred feet higher on the dividing ridge.

Some 50 miles to the eastward, within the limit of the Tehuantepec depression, across the great Mexican and Central American plateaus, there is the pass of San Fernando, on the proposed line of the Tonala and San Juan Bautista railway, which has a height of only 2,681 feet, with a broad baselevel on the Gulf side at from 2,350 to 2,250 feet above the sea. The pass from the gulf of Honduras to the Pacific ocean is also reduced to about 2,700 feet.

Declivity and Terraces of the Valleys descending from the high Plateaus

The valleys descending from the high tablelands of Mexico afford an opportunity for studying geomorphy such as is not seen in eastern America, on account of the greater degradation of the inferior plateaus of the east, which have been so modified that the important valleys no longer present immature or youthful forms.

The Mexican railway between Vera Cruz and the City of Mexico passes through one of the grandest stretches of scenery in the world, and the beauty is due to the magnitude and youthfulness of the geological forms. The valley leaves the highlands near Atoyac at an elevation of 1,512 feet above the sea and extends for a distance of 40 miles in a direct line, where it ends in an amphitheater, near the head of which is Esperanza, on the margin of the plateau at an altitude of 8,042 feet. This valley of the Rio Atoyac (a tributary of the Rio Blanco) and the Rio Blanco may be widened out to a breadth of two miles or more where tributaries join it, so that the large cities of Cordova and Orizaba are built on the floor of the valley. The valley is bounded by steeply rising mountain slopes which are so modified as to indicate that their age is far beyond the canyon stage. The floor of the valley shows at least four great pauses, each of sufficient length to allow of the production of extensive baselevels of erosion and a vast number of similar small steps, the gra-

* J. G. Barnard and J. J. Williams: Report on Isthmus of Tehuantepec, Appleton's, 1852.

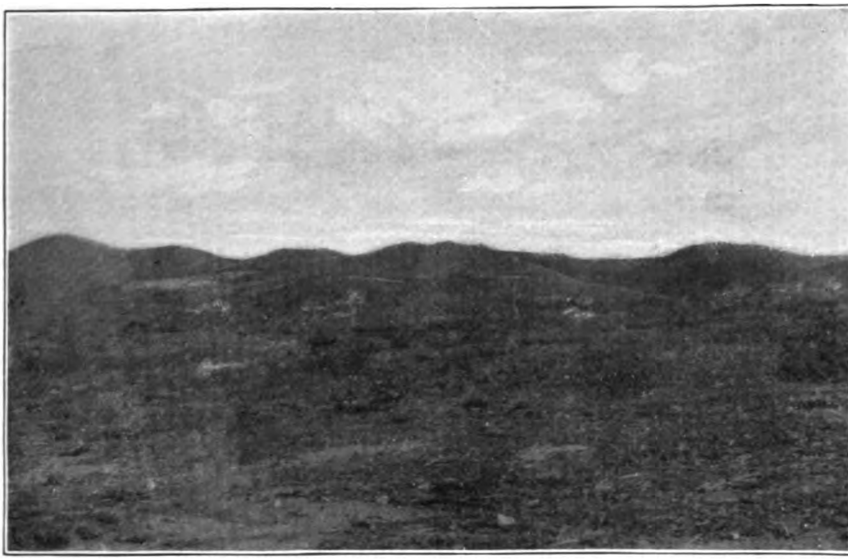


FIGURE 1.—SANDSTONE DIVIDE ERODED INTO HUMMOCKS

FIGURE 2.—ROCKY PORTAL (TO THE LEFT) AND NORTHERN END OF CHIVELA GEOLOGICAL CANAL

DIVIDE OF THE TEHUANTEPEC ISTHMUS

FIGURE 1.—FALLS AT ATOYAC

FIGURE 2.—FALLS AT BARRIO NUEVO

FIGURE 3.—DELTA TERRACES NEAR OHO CALIENTE

WATERFALLS AND TERRACES

dients of whose surfaces are very gentle. Thus, for a distance of 10 miles below Orizaba, the mean slope is 72 feet per mile, but this is made up of a number of steps, the surfaces of which are inclined very much more gently than the average slope given. For many miles above and below the section referred to in figure 1, the declivity averages 150 feet per mile.

For the uppermost 4 miles the slope is 600 feet per mile, but of this mean there is a descent of 1,500 feet in the first mile.

Of the greater steps, below the first of 1,500 feet, the most noticeable are those below Maltrata, Fortin, and Atoyac, where the great baselevels are separated by 500 feet or more. Their margins are everywhere in process of being incised by the streams which have not yet had time to cut the canyons farther back than a quarter or a half of a mile. In these canyons are narrow cascades of a hundred or two hundred feet in height. Even the great canyon, leaving the edge of the tableland, near Esperanza, is

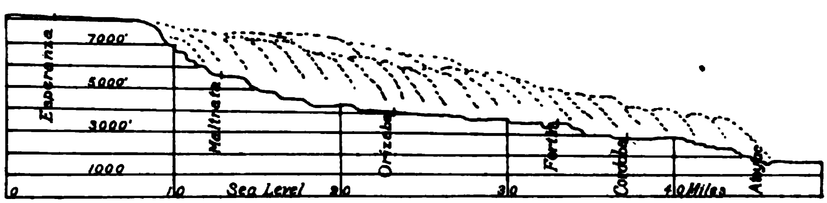


FIGURE 1.—*Section along the Mexican Railway.*

In direct distance and showing some of the baselevels and inferior steps which characterize the slope of the valley.

less than a mile long. Illustrations of the canyons, with their falls, may be seen in plate 4, figures 1 and 2, which show cataracts descending from the baselevels at Atoyac and near the city of Orizaba. The falls at Atoyac are nearly a hundred feet high, and descend through a short canyon from a terrace plain of the valley.

The smaller steps which characterize the floor of the valley are often from only a few feet to 20, 40, or more feet apart. Their surfaces are frequently very extensive and appear to the eye nearly level. On account of the surface creep or washes, the terraces frequently merge into a sloping surface, but the terrace character is preserved in the more favored spots. Of the more prominent steps, 9 were measured between Cordova and Atoyac in a distance of 8 miles. These steps represent changes in the baselevel of erosion. As the streams descend from one platform to the next they are characterized by rapids. The surface of the terrace plains is composed of rounded gravel, or this with loam, which may have a depth of more than 30 feet. Even this loose material has not been removed from the floor of the valley, but only from the newly formed valleys or canyons near the margins of the succeeding platforms, thus showing the elevation of the recent baselevel of erosion; as the deposits, which were not formed at sealevel, could only have been accumulated by the streams depositing their loads in sluggish waters or by their meandering over the floor of the plains when these were reduced to the baselevels of erosion. The gravel-covered floors are seen up to an elevation of 6,500 feet above Maltrata, and after passing through the canyon to near Esperanza, water-worn gravels occur on the edge of the plateau at about 8,000 feet above the sea.

In proceeding from Vera Cruz by way of Jalapa to the summit of the Mexican plateau (about 8,200 feet), the road, after passing the coastal plain, ascends over various baselevels of erosion (which are noticeable upon the face of the escarpment at altitudes of about 2,550, 3,650, and

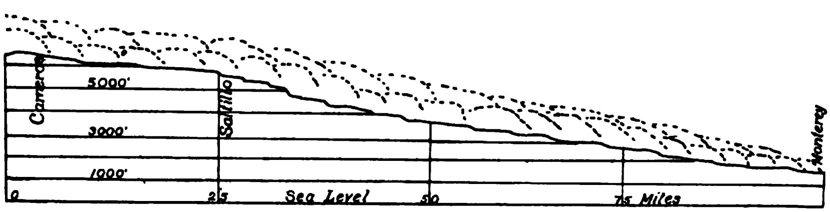


FIGURE 2.—*Section between Saltillo and Monterey.*

Showing steps in the valley.

4,300 feet), above which it passes up heavy grades along the face of the plateau, and near the summit it enters a canyon, which is excavated out of basaltic lavas about half a mile in length.

Beyond the abrupt margin of the tableland the country, as far as Puebla, is similar to that beyond Esperanza—that is, so level that it appears flat to the eye, but crossed by ridges already referred to. The surface is more or less covered with layers of wind-blown volcanic ashes. Beneath it there is commonly a loam with layers of water-worn pebbles or again with fragments of volcanic rocks. Very wide areas are distinguished by marls of lacustrine origin.

The northeastern portions of the plateaus of Mexico have a character similar to the region westward of Vera Cruz. The valley descending from Catorce (6,000 feet) to Saltillo and Monterey illustrates a succession of baselevels with short canyons cutting backward into the margins of each of these steps. In a general way, these are illustrated in figure 2. The mountain ridges bounding the plateau valley, before leaving the table-land, are from 2 to 4 miles apart, and are composed of Cretaceous limestones bent and folded in such perfect flexures as are rarely seen elsewhere. The descent from 6,000 to 5,400 feet is over broad terraces and steps, where the valley falls more abruptly from step to step, but each of these terrace steps widens out again on approaching their frontal margins. Terraces or deltas were frequently seen, as shown in plate 4, figure 3, between the elevations of 4,000 and 3,750 feet, near which the streams descend through a succession of canyons for 12 miles along the windings; but in the valley there are many terraces; 7 were measured, the margins of which are dissected by the wilder forms of the canyons. This section reaches down to about 3,000 feet above the sea. Baselevel plains were noted as having considerable developments at 2,600, 2,500, and 2,300 feet, and others were also observed at lower levels, until the extension of the coastal plains of Monterey was reached at 1,700 feet above tide.

The same kind of baselevel plains occurs at even higher altitudes than that of the general Mexican plateau. Thus at Salazar, 25 miles west of the City of Mexico, a baselevel of 10,635 feet is reached. This valley-plain is a mile wide, bounded by spruce-covered mountain ridges. The descent from it, on both sides, is abrupt, and the margins are incised with short canyons. In proceeding northward, the first descending step is 300 feet to a broad baselevel below. Following the railway from the Salazar summit down to Maravatio (6,700 feet), 114 miles distant, twelve distinct baselevels of the greater types alone were noted. The descent from the margin of one platform to the next varied from 200 or 300 feet to 100 feet or less, and generally the descent was through a *barranca* or canyon (seldom or never a mile long) to small valleys rapidly broadening out into the lower plains from 2 to 4 miles wide. The floors of these plains commonly consisted of layers of loam, very often underlaid by gravels, which also frequently appear at the surface. Some of the loams consist of volcanic ashes. The loams are often replaced by lacustrine marls. North of Puebla (9,000 feet) similar short, youthful canyons are being excavated across the higher ridges.

On the Tehuantepec isthmus there are fine illustrations of new canyons being formed at low elevations, for from the marginal plains of the geological canal across the divide at 778 feet above the sea there are short canyons descending 350 or 400 feet.

From all that has been seen of the elevated baselevels of erosion, even up to nearly 11,000 feet, and of the various steps in the valleys being covered with gravels and loose materials, and from the general feature of short canyons retreating into the edges of the various steps, whether of terraces or greater baselevel (of erosion) plains, the hypothesis of the recent elevation of Mexico seems to have become an established theory.

Geological Basement of Mexican Topography

The Mexican plateau is very extensively underlaid by rocks of the Cretaceous formations, and consequently it appears that the region was generally reduced to sealevel about the close of that period, so that the older features scarcely affect the topography due to the late changes of level of land and sea. To the late Cretaceous or early post-Cretaceous denudation is due the reduction of the older highlands to base-plains, often only a few miles wide and separated by ridges, which are frequently themselves the remains of higher baselevels of erosion. The plateau valleys are often hundreds of miles long, and are frequently connected with each other. These post-Cretaceous baselevels, however modified by more recent accumulations, often of lacustrine origin, now constitute the plateaus of at least the eastern-central portion of Mexico. The formation of this topography, being in part modified by lacustrine deposits, must have lasted for a long time, perhaps throughout a considerable portion of the Tertiary period. Valleys such as those below Esperanza and Catorce, from 40 to 70 miles long and excavated out of the margins of the great plateau, represent the molding of physical features during greatly changed baselevels of much more recent date and of comparatively short duration. Afterward the excavating forces became largely restricted in their actions, and the valleys were partly occupied by deposits accumulated either in embayments or over flood-plains of the valleys, reduced to or beneath baselevel of erosion. The subsequent conditions have favored the production of vast numbers of terrace steps, or a succession of inferior baselevels, often molded out of loose materials, and now having short canyons retreating into them.

The basement of the coastal plain is largely composed of light colored or variegated limestones and marls which are more or less fossiliferous. Some of these beds are referable to the Miocene period, but others are said to contain Miocene forms more or less commingled with Pliocene and recent species,* but the different horizons have not been separated by the Mexican geologists. That the older Miocene strata may be extensively succeeded by newer Miocene or Pliocene beds does not seem improbable, for deposits of the later period were found by the writer in the Tehuantepec isthmus. Whether or not true Pliocene beds commonly succeed the older Miocene formations, the Tertiary light colored lime-

*José G. Aguileria by Ezequiel Ordoñez: "Datos para la Geologia de Mexico." Mexico, 1893, p. 40.

stones form a physical unit beneath the coastal plains of the Gulf of Mexico, and are unconformably succeeded by the mechanical deposits, which are of much importance and which will be considered later.

Older Geology of the Tehuantepec Isthmus

The backbone of the Tehuantepec isthmus consists of a dark blue semi-crystalline limestone abounding in white quartz veins. The rocks are very much dislocated and crushed. They are similar to the limestones in adjacent parts of Mexico, which the Mexican geologists assign to the Cretaceous period.* This formation gives rise to the bold interrupted ridges of the divide rising above the baselevels from 600 to 1,000 feet higher. These limestones form two or three ridges and several outliers. Along the Tehuantepec river and other localities gneisses appear beneath the limestones. The topographic forms of these and other occasional older rocks are involved in the sculpturing which affected the limestones, and accordingly their features have not a distinct importance. The Pacific slope of the limestone ridges is principally composed of dislocated and metamorphosed shales. The shales between the bold limestone hills become like hydromica schists. Apparently occupying a basin in these shales there is a soft shaly laminated sandstone slightly crystalline with quartz veins. These deposits form the surface of the divide, beyond which, upon the Gulf side, the sandstone and shales are less metamorphosed. The margin of this zone, which corresponds to a baselevel, is incised with canyons. The valley along the railway, drained by the Malatengo river, is about 4 miles long in a direct course and descends about 400 feet to the coastal plain, which extends up the valley of the river. The bolder features occur where the canyon cuts through thick-bedded quartzite-looking rock which rises out of the shale formation of the district. Between this point and the Jaltepec river there are some other outliers of decayed gneiss and of limestone, rising through the sandy rocks of the inner portion of the coastal plain, which is covered by superficial deposits.

Beyond the Rio Jaltepec there are occasional hills of whitish compact limestones, rising to a height of perhaps a hundred feet, which are the remains of an extensively denuded surface. These beds were tilted to considerable angles before the general denudation of the region. In appearance and physical position these hills of limestone so closely resemble the white limestones of Tertiary age west of Vera Cruz and of the West

* Over a large portion of Mexico surveyed there is a remarkable absence of sedimentary and calcareous rocks older than the Cretaceous period, although limited exposures of Carboniferous formations have been discovered in Chiapas.

Indies (Lower Miocene or Oligocene) as to suggest that they had their origin at a period not distantly separated from that of the Antillean limestones. Casts of *Corbis* and other shells were obtained, but the species were not determinable. However, the age of the rocks is newer than the Cretaceous limestones and the shales of the Tehuantepec isthmus, some of which, at least, are probably Eocene.

In the study of the geomorphy of the Tehuantepec isthmus we have thus seen that the great general period of the degradation of the country to the baselevel of erosion affected the Cretaceous limestones (and the few remnants of older rocks) and the subsequent formations of shales, sandstones, and compact white limestones. Thus the modern history of the physical changes does not date back further than the extensive low continental conditions of the early or mid-Tertiary period, although more recent faultings and thrusts may have brought the mountain zone into greater prominence.

The volcanic features of Sierra Misappe and the cone of Tuxtla, on the southern coast of the gulf of Mexico, adjacent to the isthmus, are in part modern, although in part they may date back to the Pliocene period, but they do not form directly an important link in the general study of the changes of level of land and sea.

Later Formations of the Pacific Coastal Plain of Tehuantepec

Subsequent to the mid-Tertiary baseleveling, which constituted the foundation of the plains of the isthmus, there has been the deposition of two other formations. The older of these is a belt of white or variegated marly limestone, containing within it water-worn pebbles of limestone, marble, gneiss, etcetera. This zone skirts the foot of the mountain region, and is itself so much denuded as to be preserved only in the more ancient hollows, which it fills, or in other protected places. These accumulations were observed to an altitude of 320 feet, and possibly the limestone in the valley of the Rio Verde, near the hot spring, at an altitude of 400 feet, may belong to the same formation.

This more or less mechanical limestone bears strong evidence of a second baseleveling of the region, which upon the more open plains is not separable from the older denudation. The altitude during the epoch of denudation was low.

The relationship of this limestone to both the underlying floor of the coastal plain and the succeeding mantle is shown in section in figure 3.

The surface formation of the plains is a reddish loam derived from the weathered rocks of the region. Along the rivers many sections are well exposed. Thus near San Geronimo station the formation consists of 2 feet of water-worn pebbles below, which are overlaid by 3 feet of the red loam. These accumulations rest upon decayed gneiss. Near by, the river exposes the gravels and loams filling an old valley, where the thickness is 50 feet without reaching the underlying surface. The thickness of the deposits usually varies from 10 to 20 feet of loam above and from 2 to 8 feet of gravel below. On the higher undulations of the plain these accumulations are sometimes wanting and low bosses of the underlying rocks come to the surface. The stratification, while often apparent, is in many places obscure, especially where the loams become case-hardened when they stand in vertical walls. In the vicinity of the rivers and of

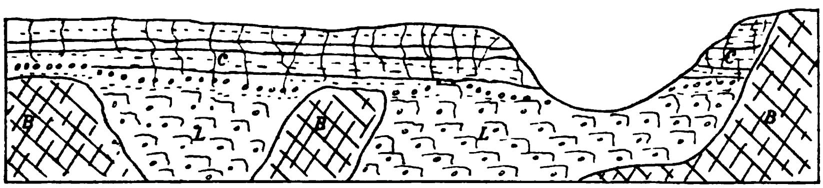


FIGURE 3.—*Section along Rio San Geronimo.*

B, Eroded surface with valleys excavated out of decayed basaltic rocks; L, Marl with water-worn pebbles; C, Gravels and loams resting unconformably upon the marls.

the mountains, the greatest amount of the gravel was seen. This formation of gravels and loams has been a great leveller of the plains by burying the old valleys and hollows; accordingly, the old courses of the streams have often been changed. Thus the Tehuantepec river leaves the broad, open plain, where its former course has been buried, and flows through a narrow channel between two high isolated hills rising out of the plains near the sea.

The formation thus described as covering the Pacific coastal plain is identical with that forming the upper surface of the Gulf plains (the Columbia), while the underlying marly limestones are regarded as the equivalent of the lower mechanical deposits occurring on the Gulf side of the isthmus (the Lafayette).

Later Formations of the Atlantic Coastal Plain of Tehuantepec

COATZACOALCOS FORMATION

Character, extent, and relations.—The reason for a nomenclature so difficult arises from the isthmus not possessing important towns which would appear upon an ordinary map, while the Coatzacoalcos river is the great feature of the coastal plain, which is extensively underlaid by the deposits here named the Coatzacoalcos formation. It is fine grained, laminated, calcareous clay of brownish color weathering to a bluish hue. Its characteristics are uniform. The stratification is horizontal, with some slight undulations. In some sections a few miles south of the Rio Jaltepec, these clays rest upon decomposed gneisses, but the underlying beds to the north are rarely exposed. These horizontal beds, near the 80-kilometer post, cover the floor of the old baselevel out of which rise the upturned beds of white limestone (noted before as probably early Tertiary). The clays were seen as far as the 35-kilometer post a point only 7 miles in direct course from the Gulf. This formation underlies most of the coastal plain for a breadth of 65 miles or more. In the railway cuts only the lower portion of the sections are composed of these clays, so that seldom more than 10 or 15 feet of their thicknesses is shown at any locality. The surface is overlaid by a mantle of Lafayette or of Columbia deposits.

Fauna and age.—A considerable number of fossils were obtained close by the 124-kilometer post, near San Lucretia (at the crossing of the Rio Jaltepec), where the altitude is 125 feet; near the 104-kilometer post, at 180 feet above the sea; at the 70-kilometer post and 35-kilometer post, at 30 or 40 feet above the sea. The fossils collected were kindly determined for the writer by Dr W. H. Dall, who gives the list as follows:

Sabella (tube) (70).*
Dentalium sp. (like *megathyris*, Dall) (70, 124).
Conus (young, like *leoninus*) (70).
Pleurotoma albida, Perry (70, 35).
Pleurotoma (like *ostrearum*) (70, 124).
Pleurotoma sp. (70, 124).
Pleurotoma (like *cedonulli*, Rve.) (124).
Pleurotoma (like *henikeri*, Say) (124).
Drillia sp. (70, 124).
Cancellaria sp. (124).
Scaphella dubia, Brod. (70, 124).
Marginella (like *cineracea*, Dall) (70).
Marginella (like *succinea*, Conr.) (70).
Olivella mutica, Say (70).
Niso interrupta, Say (70).
Scala retifera, Dall (70).
Phalium globosum, Dall (70).
Dalium (like *solidum*, Dall) (124).
Daphnella sp. (fragment) (70).
Glyphostoma gabbi, Dall (70).
Mutulella fusiformis, Gabb (70).
Fusus sp. (fragment) (70).
Murex sp. (fragment) (70).
Trophon sp. (like *triangulatus*, Cpr.) (70).
Trophon sp. (124).
Phos sp. (70, 35).
Mitra (like *fulgurita*, Rve.) (70).
Mitra striolata, Lam. (124).
Cancellaria (like *modesta*) (70).
Cancellaria centrota, Dall (70).
Lunatia sp. (124)
Natica (like *canrena*) (70).
Solarium sp. (70).
Xenophora caribæa, Petit (70).
Pecten (like *glyptus*, Verr.) (70).
Amusium lyoni, Gabb (70).
Pinna sp. (fragment) (70, 124).
Ostrea sp. (fragment) (124).
Loripes sp. (young) (70).
Astarte smithii, Dall (70, 124).
Arca spenceri, Dall (70).
Leda acuta, Conr. (70).

* The figures refer to the nearest kilometer post along the line of the Tehuantepec railway.

Of the fossils found, 34 per cent are not known to be living forms. This feature causes Dr Dall to regard the formation as being of the late Miocene or Pliocene period, but the collection represents an off-shore or deep-water formation.' As the character of the living fauna of the deep waters of the gulf of Mexico are only partly known, he suggests that the fossils collected represent a much larger percentage of living forms than those named in the list.

This Coatzacoalcos formation is a most valuable discovery in the Central American and West Indian region, as in no other portion of it has a fauna of such Pliocene appearance been made known. From the physical standpoint the occurrence of the fauna is most important, for it shows that the isthmus was submerged to at least several hundred feet during more or less of the Pliocene if not in the late Miocene period, when the West Indian region and southeastern part of the North American continent were elevated and subjected to a long period of denudation, which produced the broad undulating plains formed at the base-levels of erosion, the remains of which now stand at various altitudes. Thus, from the paleontological as well as the physical existence, it appears that so much of the gulf of Mexico as existed during a portion of the Mio-Pliocene period was connected with the Pacific ocean through the Tehuantepec straits. It is not improbable that there may have been many Pliocene connections between the Gulf and the Pacific ocean throughout a distance of 200 miles during the greatest submergence.

SOME UNASSIGNED DEPOSITS OF THE COASTAL PLAIN

At the 27-kilometer post, about 4 miles directly distant from the Gulf, there is a small knoll rising 15 feet, composed of dark soft clayey marl with an included bed of 3 feet of shale, which has a dip of 30 degrees northeastward. On the west side of the cut a fault occurs. Near Jaltipan (42-kilometer post) there are several undulations, where the low hills (about 170 feet above the sea) are composed of arkose, while the hollows between them are occupied by the Columbia (?) formation. The exact geological positions of these isolated formations have not been determined.

Lafayette and Columbia Formations in Mexico

IN NORTHERN MEXICO

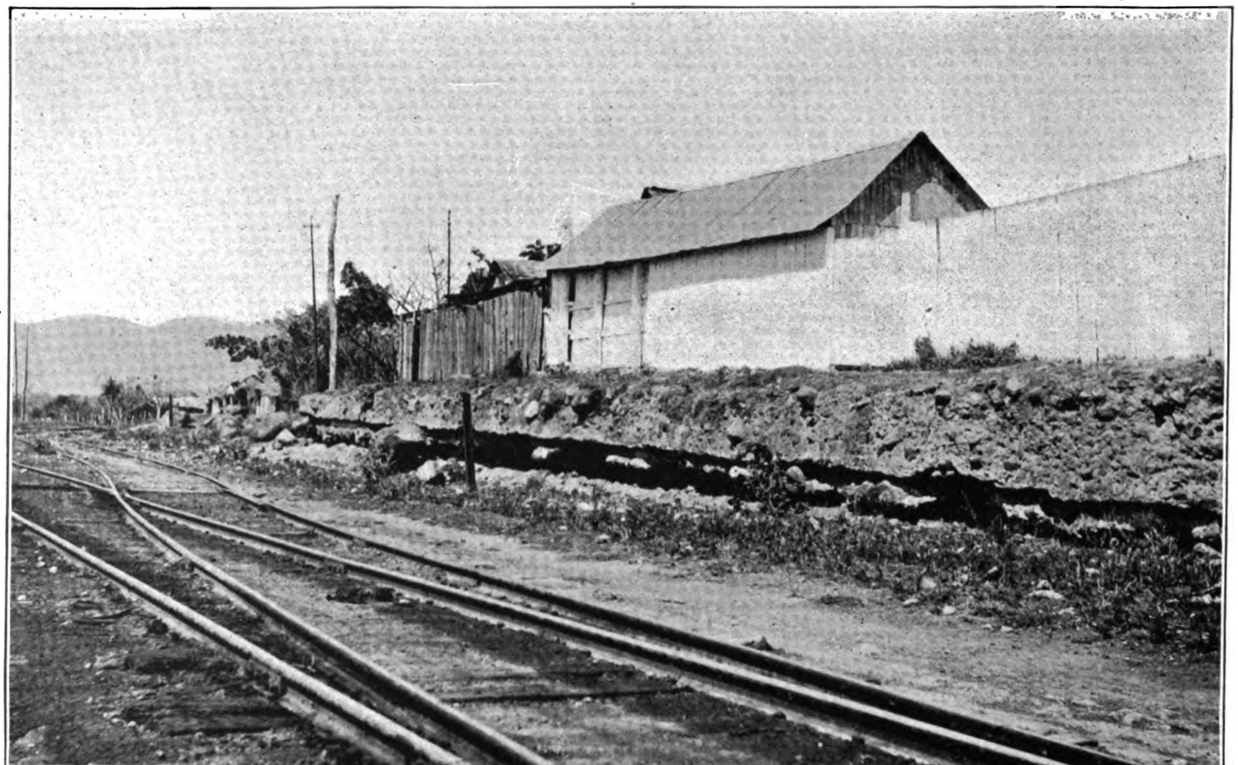
The extended investigations of Mr W J McGee have given us a systematic knowledge of the Lafayette and Columbia formations, which are very widely distributed over the coastal plains of the United States.*

* W J McGee: The Lafayette Formation. Twelfth Ann. Rep. U. S. Geological Survey, 1892, pp. 347-521.

These formations cross Texas and extend over the Mexican plains. The Lafayette reaches an altitude of 1,700 feet at Monterey. How much of the mechanical deposits in the higher valleys belong to the Lafayette series is not known. The two formations have similar characters, being composed of red or chocolate colored loams, with bedding often indistinct, except where traversed by lines of pebbles. The surface is commonly case-hardened, so that the materials stand in natural walls, subject to more or less vertical cleavage. The underlying portion of both series frequently consists of water-worn gravel, especially in the vicinity of great valleys. The accumulations appear to have originated by the rapid deposition of the residuum left from the decay of rocks of various ages, from those of the Archean crystallines to the Tertiary limestones. As the earthy products of rock decay generally resemble each other, so the Lafayette and Columbia deposits have remarkably uniform characteristics. Neither formation is usually more than 20 feet thick, except where it fills buried valleys. The Columbia material is derived from that of the Lafayette, the surface of which was enormously denuded before the latter period. The newer formation differs from the older principally by the finer grained deposits or by the somewhat more perfect separation of the sandy particles from the unassorted mass.

IN CENTRAL-EASTERN MEXICO

Landward of Vera Cruz the Geological Survey of Mexico has mapped a belt of Tertiary rocks underlying the coastal plain. Sections of these may be seen along some of the streams, especially those crossed by the Interoceanic railway between Vera Cruz and Jalapa, whère the white marls and limestones frequently come to the surface. The limestones appear at various points as far as El Palmar, about 15 miles in a direct distance from the sea, where the altitude is about 2,350 feet. The strata of the white limestones are more or less upturned, and they are succeeded by thin horizontal layers of white marl, which are frequently noticed beneath the red loam near the coast. Higher up the escarpment, at about 2,800 feet, the marl, having a thickness here of from 2 to 6 feet, is horizontal, and rests upon the eroded surface of basaltic rocks, as shown in section in figure 4. Owing to the similarity of material, this upper marl is not always easily identified from the lower Tertiary beds. The basaltic rocks along this escarpment are in close proximity to several great volcanoes, which have been in activity since the Pliocene period. At the low altitudes, and at many places higher up, where the marl does not form the surface, the country is covered with red loams, or these underlaid by gravels. While the line of the Interoceanic railway follows a promontory of the Mexican escarpment, the Mexican railway passes up



EXPOSURE NEAR PASO DEL MACHO

Showing upper boulder and gravelly tuffaceous beds succeeding the lower tuffaceous loams an indentation in the margin of the plateau in front of the volcanoes of Orizaba and of Sierra Negra. The marly beds along the former road are here either replaced by loams and gravels (more or less volcanic) or are obscured by them. The plains in this district are about 50 miles wide, and have their surfaces only slightly sculptured by atmospheric agents. At Solidad, about 25 miles from the coast, and at an altitude of 300 feet, there is a section about 40 feet in height shown in the river bank. The lower portion consists of a fine light colored tuffaceous deposit in horizontal beds from 5 to 6 feet thick. It contains only occasional small pebbles. The materials consist, more or less, of volcanic ashes water-deposited, and forming a sort of tuffaceous accumulation, which often appears at the surface as far as Paso del Macho, near the foot of the mountains. Beyond this station there is a volcanic tuff containing angular stones, and some great volcanic blocks derived from volcanoes on the edge of the high plateau. Just before entering the great mountain valley at Atoyac, in a lateral valley this angular volcanic debris, which is 10 or 12 feet thick, rests upon water-worn gravel containing rounded boulders, some of which are 2 feet in diameter. This lower gravel is superimposed on the white limestones that rest against the edge of the escarpment and which are referred to the older Tertiary period.

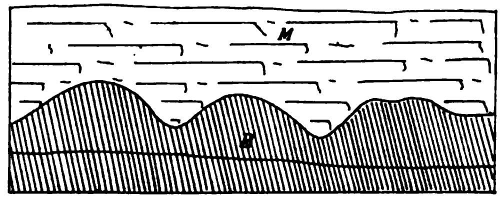


FIGURE 4.—*Section at Chavarillo.*
Showing the junction of the eroded basaltic rocks (*B*) and overlying marl (*M*).

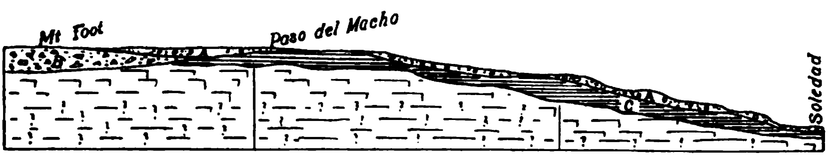


FIGURE 5.—*Section between Solidad and the Mountains.*

Showing superficial deposits of the coastal plains. *A*, Superficial gravel referred to the Columbia formation; *B*, Angular débris overlying gravel; *C*, The Lafayette tuffaceous lower loams unconformably beneath the Columbia, and above older Tertiary limestones.

Overlying the very much eroded surface of tuffaceous loam in the river section of Solidad there is a formation of coarse loose gravels from 5 to 10 feet thick, with pebbles as large as 8 inches in diameter. The upper part contains occasional rounded boulders of 3 or 4 feet in length. The formation becomes more tuffaceous and forms much of the surface of the country to near the foot of the mountains. The structure is well shown in plate 5. These boulders are volcanic, and they were probably blocks thrown out of the volcano of Orizaba. Many of them have been rounded by water action, while a few, from 3 to 5 feet in length and near the mountains sometimes 10 feet in length, are angular. These boulders were lodged in the sea while the tuffaceous deposits were being assorted by the waters. Their appearance upon the surface is now due to the atmospheric denudation removing the fine materials and leaving gravel-covered surfaces or pavements of boulders. Below Solidad the gravel is mixed with red or chocolate-colored loams. These red loams and underlying gravels cover the undulating plains for nearly 25 miles to the sand dunes which separate the plains from the coastline. The relationship of all these superficial beds is shown in section in figure 5.

From this preliminary survey it may be observed that the lower gravels at the edge of the mountains appear to have been a delta deposit accumulated on the eroded surfaces of the older Tertiary limestone when the region became depressed to sealevel. The angular deposits represent great volcanic eruptions burying the gravels, and (with the materials more or less weathered) they resemble the till of glacial regions. These volcanic eruptions, of which the lava is seen in other localities, are provisionally regarded by Mexican geologists * as belonging to epochs from the Pliocene period to modern days.

Resting on the volcanic rocks there are extensive deposits of tuffaceous loams, which correspond in position to the Lafayette of the north, that rests on old Miocene surfaces. These tuffaceous accumulations are superficially eroded, as is the typical Lafayette, and they are succeeded by gravels and red or chocolate-colored loams of the surface, which have not been subjected to a great amount of erosion, as is the case with the Columbia formation. This succession makes it not unreasonable to correlate the deposits described with those of the Lafayette and Columbia of northern Mexico and Texas. Their accumulations appear to rise to a similar height of nearly 1,600 feet, and it is possible that some of the gravels and red loam of the mountain valleys of higher altitudes may belong to the Columbia period.

ON THE GULF SIDE OF THE TEHUANTEPEC ISTHMUS

On the coastal plain of the Tehuantepec isthmus the Lafayette and Columbia formations are extensively developed. At the 17-kilometer post of the Tehuantepec railway, two miles in a direct course from the Gulf, in some cuts through ridges from 25 to 30 feet high, the juxtaposition of the two formations is well illustrated, as in figure 6. The Co-

* José G. Aguilera by Ezequiel Ordoñez: Datos Para la Geología de Mexico. Also orally mentioned to the writer by Señor Aguilera.

lumbia red loams are from 5 to 10 feet thick in this section. with the underlying fine quartz gravels (mostly subangular) of about equal thickness. It rests unconformably on the Lafayette red loams, in which there is a streak of clayey matter one to two feet thick. The hills immediately on the coast are covered with loose sand in the form of dunes. Between the coast and the mountain zone this Columbian formation occupies all the lower depressions of the undulating plains, while occasional ridges of the Lafayette red loams and gravels rise through them. At Jaltipan, as noted before, the hills are composed of arkose, which may be a local representation of the Lafayette. While the Columbia and upper loams prevail eastward of the Jaltepec, beyond that river, in the higher hills, the Lafayette is frequently observed with its surface eroded and succeeded by the Columbia gravels and loams. These accumulations are best exposed between the 146 and 152-kilometer posts. The Lafayette is typically a red sand or sandy loam, more or less distinctly laminated, although frequently no bedding is seen. It sometimes includes layers of sandy clay, which may be 4 feet thick. In many places the base of the bed is represented by gravel, which, however, may appear in other portions of it. When no other structure is seen, a vertical cleavage is apt to prevail, which, in this as in other Lafayette and Columbia loams, is a physical distinction from the underlying Coatzacoalcos formation. These red loams are also liable to be case-hardened. The stratification is nearly horizontal, although varying two or three degrees. Near the 136-kilometer post the Lafayette formation is notably faulted with a local dip of 10 degrees, and near by there is a dip of 6 degrees. On many portions of the coastal plain the Lafayette is wanting, and the Columbia rests directly upon the Coatzacoalcos formation, while on the inner portion of the belt no unconformity between the Lafayette and exposed underlying Coatzacoalcos formation was recognizable; but this feature may be due to the failure of observations.

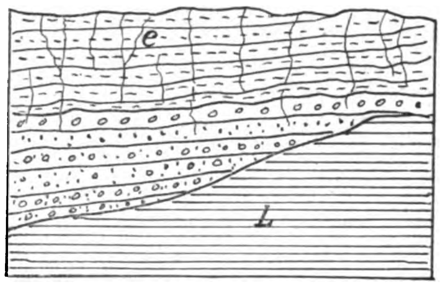


FIGURE 6.—*Junction of the Columbia (C) and Lafayette Formations (L).*

As shown at the 17-kilometer post of the Tehuantepec railway.

After passing up the canyon of the Malatengo the baselevel step, above 700 feet, is characterized by a country abounding in hills 50 feet in height and separated by broad, shallow depressions. These higher hills are composed of red loams and gravels which are referred to the Lafayette. The pebbles consist of quartz and sandstone, as before described. The hollows are occupied by the unconformably overlying materials referred to the Columbia. In some localities, as in the vicinity of the 201½ to the 208½-kilometer posts, there are sections exposed to a depth of 30 feet, showing nearly this thickness of perfectly rounded boulders or more properly large gravel—in size often two feet in diameter—which is remarkable, as the locality is too far from the higher lands to suggest their transportation by ordinary floods, but they lie in what was the pathway of the ocean currents passing through the former straits of Tehuantepec. These gravels rest on the sandstones referred to before as of probably early Tertiary age.

The character and the unconformable succession of the deposits, wherever found resting on the eroded Tertiary formations, and the similarity of the remarkably uniform surface features, point to the distribution of the American Lafayette and Columbia formations throughout Mexico to the Tehuantepec isthmus, although the commencement and ending of their epochs may not have been perfectly synchronous over the extreme limits of distribution.

The extensive erosion of the surface of the Lafayette is an important feature, and its assigned equivalent on the Pacific side—the pebble-bearing marls at the base of the mountain—has been mostly removed, as well as all of the Tertiary stratified deposits, in this case due to the denudation of the two great periods of elevation.

Terraces on the Coastal Plains

Terraces or terrace plains and baselevels of the higher valleys have already been described. The inclined surface of the coastal plains from the sea to the mountains is not distinguished by a uniform rise, but is made up of a number of steps. The margins of the terrace platforms are characterized by sweeping hills and knolls, often from 50 to 100 feet high. When these are ascended the country is again seen to be a rising plain, with the inferior terraces often obscured, but these may be preserved in the shallow valleys. Among the more conspicuous terrace steps and plains there is one of about 300 feet above the sea, just east of Solidad, and the front margins of some of the more noticeable higher terrace plains were found at heights of 450, 625, 800, 1.120, 1,400, and 1,560 feet above sealevel, the last named being the summit of the plain.

The coastal plain of the Tehuantepec isthmus is characterized by similar steps, but the margin of the plain being reached at about 325 feet above sealevel, only steps of insignificant height occur. On the base-level plains of Chivela, in the mountain region, there are terraced plains at several altitudes between 700 and 850 feet, the last of which is 75 feet above the floor of the geological canal across the divide.

Upon the Pacific coastal plain steps similar to those upon the Gulf side were observed. These were most easily distinguished by their equivalent terraces within the river valleys. Along the San Geronimo river the terraces were seen at 250, 275, 300, and 325 feet above the sea; in the Rio Tehuantepec valley up to 400 feet, and in the Rio Verde up to 375 and 400 feet. On the isolated ridge facing the city of Tehuantepec there are erosion shoulders or sea-cliffs and sea-caves at 400 feet. Sea-caves were also seen at other localities.

Geological Canal of Chivela

Excavated out of the earthy sandstones which characterize the summit of the divide, at a height of from 900 to 1,000 feet above the sea, there is a depression of less than a mile long between the two sides of the summit (see plate 3, figure 2, page 16). The floor of the narrow canal coalesces with the terrace plains of Chivela on the Gulf side. On the Pacific side there is a more abrupt descent across the lower remains of baselevels. The floor of the canal is 776 feet above the sea and is covered with from 4 to 8 feet of gravel, composed of quartz and soft sandstone, the latter being well water-worn, derived from the adjacent hills. These adjacent hills rise at an angle of 15 to 20 degrees, and the same surface gravel, thinly scattered over them, was seen to a height of 150 feet at least above the floor of the canal; but the broad baselevel between the higher mountain knobs and now denuded undulating hills. illustrated in plate 3, page 16, was evidently swept over by ocean currents passing through the lately existing Tehuantepec straits. The elevation of this canal has been so recent that only short canyons have been cut into the baselevels and terrace plains, and the features of the canal itself have not been destroyed by the subsequent atmospheric denudation.

At the pass of Tarifa (Santa Cruz), a dozen miles to the eastward of Chivela, there is a depression similar to that just described, through which the formerly proposed ship railway was surveyed. On the Gulf side of the Tarifa pass there are also plains, at about the same altitude, to which those from Chivela extend. East of the Tarifa plains the mountain regions rise higher than in the vicinity of the canal. There are other current-swept depressions in this region, though probably at higher altitudes. Such a one is to be found some 60 miles or more to the eastward, at San Fernando pass, which is at the summit of the proposed Tonala railway.

Biological Evidence of Interoceanic Connection

There is a striking resemblance between the littoral fishes, mollusks, and echinoderms of the West Indian waters and those of the Pacific, according to the studies of the late Dr G. Brown Goode, although there is absolutely no resemblance between the deep-water fishes on the two sides of Central America. The intermingling of the molluscan fauna was long ago pointed out by Dr W. B. Carpenter, who identified 35 species out of 1,400 Pacific forms as occurring on the Atlantic side of this region. Subsequent discoveries have increased the number to about a hundred species, according to Mr Charles T. Simpson. This distribution of modern fauna was only to be expected, after studying the physical and geological structure of the region, or *vice versa;* but it is satisfactory that both lines of evidence have been obtained.

Summary and Conclusions

The coastal plains of Mexico are continuous with those of the United States, and rise to a height of 1,600 or 1,700 feet before they abut against the foot of the high plateau; but on the inner margins these plains are only about 325 feet above the sea on the Tehuantepec isthmus.

The high plateaus of 6,000 or 8,000 feet or more were formerly broad baselevels, surmounted by cerros, ridges, and volcanic cones. On the Tehuantepec isthmus the mountain zone is reduced to a breadth of 25 miles and a height of 1,000 feet, and it is crossed by short channels at lower altitudes. The margins of the higher plateaus are penetrated by deep valleys for a distance of 40 or 60 miles or more, showing features of denudation very different from the broad baselevels of the plateaus, and also marking a later epoch of a very much shorter duration and more recent than some of the Pliocene volcanic eruptions.

The gradients of the valleys may average from 75 to 150 feet per mile, and in the uppermost few miles of their amphitheaters as much as 600 feet per mile; yet they are not simple slopes, but are characterized by several greater baselevels of erosion and a vast number of terrace steps of inferior height which are covered with gravels and loams that refill in part the older valleys. The edges of these baselevels and terraces are dissected by deep, narrow canyons of too recent origin to have penetrated any considerable distance.

These forms impress three great features of erosion upon the modern topography, namely: (1) The old baseleveling of the outlines of the plateaus, though in part molded before it was completed in post-Cretaceous times; (2) the excavation of large valleys, which, however, did not dissect portions of the coastal plain observed, thus indicating an inferior elevation at that time, with various baselevels showing pauses in changes of altitude; and (3) the subsequent submergence of the Columbia and terrace episodes, followed by the late elevations and development of modern canyons.

The second class of erosion was modified in the Tehuantepec isthmus where the low dividing ridge was a broad baselevel channel or current-swept strait, indicating that the lower altitudes were depressed to near or below sealevel during part of the period, while afterwards it was dissected by the short channels forming the canals of the Pleistocene epoch.

The older Tertiary limestones of the coastal plain were greatly denuded before the deposition of the succeeding marls, gravels, and loams, with volcanic debris, in the Lafayette or provisionally late Pliocene epoch. On the Tehuantepec isthmus, resting upon the upturned and eroded surfaces of older strata, the Coatzacoalcos formation occurs in horizontal beds. This contains an off-shore or deep-water fauna belonging to the late Mio-Pliocene period. Thus the isthmus is shown to have been a strait during a period when the West Indian and adjacent portions of the continent were elevated and subjected to a long-continued denudation. The Lafayette formation seems to have succeeded the Coatzacoalcos in the Tehuantepec region, without any considerable physical disturbance intervening, but on the Pacific side the mechanical materials were replaced by a white soft limestone, with water-worn pebbles. The denudation following the Lafayette epoch was here at baselevel and has not only widely removed this formation, but even affected the underlying formations. The Lafayette formation extends over the coastal plain of central-eastern Mexico to the foot of the tableland.

The Columbia formation, of similar materials, and including volcanic blocks, rises to an altitude as great as that of the Lafayette. Some of the accumulations in the higher valleys, whether estuarine or fluviatile (deposited at low baselevels) occur up to heights of nearly 8,000 feet, and may belong to this mid-Pleistocene epoch, as we do not yet fully understand the limits of the continental and mountain movements which have given rise to the recent differential elevation of the plateaus and the higher parts of the coastal plains.

The coastal plains are characterized by terrace-steps which have their margins sculptured into hills, and the streams descending from one platform to another form small canyon-like valleys.

The baselevel of the Tehuantepec divide is dissected, at heights ranging from 776 to 820 feet, by short geological canals, the floors of which are covered by gravel which forms continuous layers with the materials of the terrace plains on the Gulf side of the ridge. This oceanic connection, or rather the somewhat earlier and broader strait, was as old as the Columbia (mid-Pleistocene epoch) and admitted the Pacific littoral mollusks and other fauna to the Mexican gulf. It also continued nearly to the modern epoch, as indicated by the shortness of the modern canyons.

Finally, as shown by the excavations of the short canyons at all altitudes in Mexico, to even more than 10,000 feet, the almost modern elevation of the region should be strongly emphasized. The molding of the low baselevel or current-swept floor of the Tehuantepec divide antedates the Columbia formation or the mid-Pleistocene depression of the locality. This subsidence was followed by a gentle elevation and excavation of the narrow short valleys, which later became geological canals. Thus the region was depressed during at least a part of the early Pleistocene epoch, when great valleys were being formed in the Antillean region and elsewhere to the east—a repetition of Mio-Pliocene conditions.

In the undulating continental movements extensive tilting of the mountain region is characteristic. How much of the recent extreme rise is due to gentle undulations from lower baselevels and how much from below sealevel has not been determined, as the features are due to both conditions. While the superficial formations of Mexico appear continuous with those of the United States, they are not relatively as much denuded by recent atmospheric actions as their stratigraphic equivalents farther north, even though of greater altitude, thus suggesting a later continuation of the upheaval in Mexico than on the coastal region of the United States.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 9, PP. 35-58 JANUARY 18, 1898

CLAY-VEINS VERTICALLY INTERSECTING COAL MEASURES

BY W. S. GRESLEY

(*Presented before the Society August 10, 1897*)

CONTENTS

INTRODUCTION

The purpose of this paper is to present a record of observations on dike-like deposits of clay and other material traversing the bituminous coal regions west of the Allegheny mountains, together with illustrations of and references to allied phenomena in other countries.

The comparative obscurity of clay-veins confines their inspection and study *in situ* almost entirely to such parts of them as are laid bare by such mine workings as these veins or dikes intersect or disturb. In other words, it is only a very small part, indeed, of a clay-vein that can be seen and examined, for a miner will cut or cross as few of them as possible. Nevertheless, many of them occur, and are of necessity cut and thus exposed in one place or another and at one horizon or another in the Coal Measures.

Definition of a Clay-vein

A clay-vein (also termed "clay-seams," "mud-seams," etcetera, by the miners) may be described in a general way as a more or less vertical, crooked, tortuous, often branching, ragged sided wall or dike intersecting a seam of coal and composed of (1) compact, indurated, clayey materials, or (2) a mixed debris of rocks, forming a breccia or a conglomeratic mass varying in width from a mere streak or film of clay to as much as 15 feet, but averaging about 10 inches.

Some general Characteristics of Clay-veins

The horizontal trend of a clay-vein may be in any direction. It may extend a few yards only or run a mile or more before being lost to sight. It is liable to branch or divide both vertically and horizontally, and even to unite again. Local swellings and sudden nips occur, and it may have toughened, twisted, spoiled, and somewhat displaced the coal or other material forming its walls. It is frequently joined to or forms part of one or more other clay-veins, thus constituting a member or branch of a system or rude network of such veins, traversing possibly an entire coal field, and being devoid of cavities and extending downward below the coal, as well as upward through the roof, to unknown distances. Clay-veins have been met at a maximum depth of about 400 feet, but probably occur at greater depths.

Detailed Description of a Typical Clay-vein

Figure 1 represents a vertical section of an ordinary clay-vein, as sketched by the writer, in a mine working the Pittsburg seam of coal in Westmoreland county, Pennsylvania, at a depth below the surface of about 300 feet. The leading features of this vein are as follows: The clay vein cuts the coal seam where it is of normal height, quality, dip, etcetera. The vein is about 1 foot in width, but splits in the roof coals and shales, detached mass of which may be regarded as a "horse" in the vein. There is a vertical displacement of the coal bed amounting to about 20 inches. Distortion and fracture of the strata or vein walls have occurred. There is local swelling of the earthy bands in the coal in proximity to the vein. Vein material is thrust in between the laminæ of the coal. The clay-vein occupies a rent or fissure in the Coal Measures. The "cleat" or vertical cleavage of the coal is twisted and deformed—"curled," as the miner terms it—on one or both sides of the vein, and often to a distance of many feet, making the coal exceedingly hard and comparatively worthless. Cracks occur in the vein walls, more or less filled with clay, pyrites, etcetera. The dip of the coal is slightly altered on one or both sides. The vein stuff is fragmentary and mixed in character, and consists of small bits of shale of varying degrees of hardness, texture, color, etcetera; of sandstones stones and grits; of lumps of whitish and yellowish limestone, often quite soft; of chips of chert, ironstone, coal, etcetera; of flakes of mica; quartz and other hard grains; with very much clayey material; with pyrite and marcasite, in crystals and streaks; and nodular concretions of the various fragments; those of pale gray shale seem to predominate.

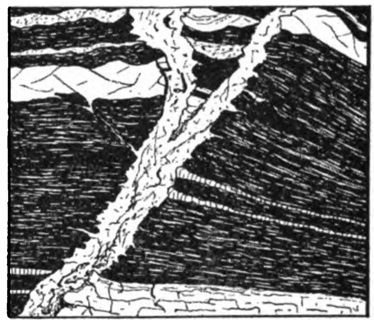


FIGURE 1.—*Vertical Section of Ordinary Clay-vein.*

One-fiftieth natural size.

The aspect of the vein stuff, when of a decidedly fragmentary or brecciated character, as viewed in the direction of the vein walls, is somewhat

FIGURE 2.—*Vein Stuff.*

Natural size.

FIGURE 3.—*Vein Stuff.*

Natural size.

roughly shown in figure 2, while the same material, viewed in the direction of the clay-vein, is indicated in figure 3, which exhibits a decidedly squeezed and drawn-out condition of the rock. This figure also shows that faulting exists in the vein stuff (see *f f'*), the walls of these miniature faults being highly polished and often striated, with slickensides. The individual fragments in the vein material have in many places undergone change in form and coloration as well as in chemical composition.

While some portions of the vein is of a brecciated character, others consist of little else than hardened clay, clay and sand mixed, or even mostly sand, these differently composed layers or zones ranging roughly parallel to the vein walls. Lumps of coal in the matrix of the veins always possess their original cleat, even though the same is distorted. Coal, when forming the vein walls, always retains a portion of the clayey vein stuff when removed, the latter being so tightly jammed into the coal as to make the two materials inseparable. Figure 4 illustrates the ragged edge of the coal pierced by tongues of hard clay-vein material in characteristic manner. The usual color of the vein stuff is gray, with irregular tinges of brown, green, yellow, etcetera. A close inspection of much of the brecciated stuff, especially when wet, presents quite pretty variegated aspects, such as are seen in polished marbles.

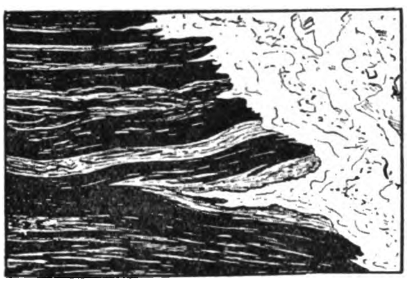


FIGURE 4.—*Coal pierced by Clay-vein Material.* Natural size.

DISTRIBUTION OF CLAY-VEINS

The mining of coal and of fireclay underlying the coal has revealed the existence of clay-veins, so far as the writer has ascertained, in an area no less extensive than that indicated by the letters C. V. on figure 5. These veins are particularly numerous in the Pittsburg coal region, as well as in parts of the Kanawha valley in West Virginia, especially in contact with the "Pittsburg" coal seam. Whether clay-veins occur where there is no coal—that is, in the "Barren series" of the coal fields, as well as in the newer and older rocks of the region affected—are questions awaiting answer. In Pennsylvania they are found entirely across the bituminous coal field, from Elk county on the northeast to Green county in the southwest. The mines in Ohio reveal them, as do those in Illinois, Iowa, Missouri, and West Virginia. In Pennsylvania they occur in probably all the seams of coal from the "Washington," near the top of the series, to the "Clarion," near its base. Much of the "Sewickley" or "Redstone" bed is so much disturbed by clay-veins of one kind or another (many of them are probably referable to washouts) as to render it worthless. Portions of the "Pittsburg" bed in West Virginia have been found so thickly intersected thereby that mining operations had to be abandoned in such areas. While they infest some districts, others,

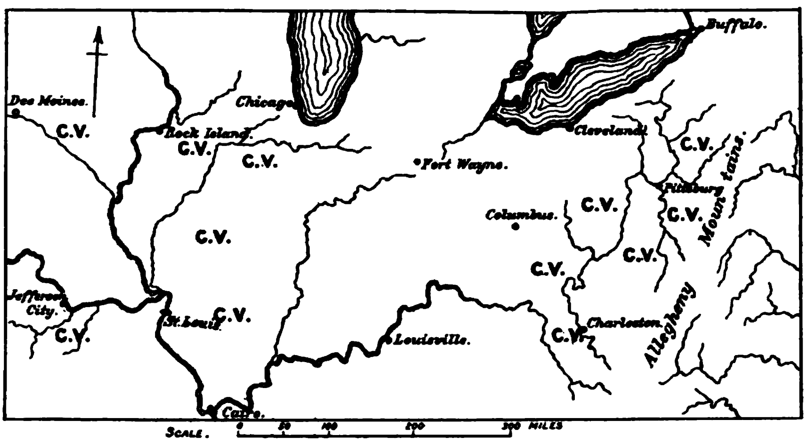


FIGURE 5.—*Distribution of Clay-veins (C. V.) as observed in Coal Seams of the United States.*

without any apparent reason, are comparatively free from them. A glance at figures 6 and 7* will give a fair idea of their distribution in localities where they are quite numerous, or fairly so, but the thin and irregular offshoots are not shown, because they are far too abundant to survey and map. Hence only the more prominent veins are plotted.

VERTICAL RANGE

By way of proof that clay-veins are not confined to the seams of coal, cases might be cited where they have been cut in the sinking of wells, air-shafts, slopes, etcetera. In connection with the mining of the Pittsburg coal in Pennsylvania, an air-shaft having a vertical height of 35 feet was sunk through a clay-vein at Grant, in that State. Clay-veins extending upward from the coal through the overlying rocks to the surface soil were laid bare at the mouth of the Forest Hill mine near West Newton, Pennsylvania, a few years ago. The same veins could be seen traversing, in a divided form, the floor of the seam, as well as the limestone below it. These facts demonstrate the existence of clay-veins,

* This figure was reduced from a plan of the mine kindly supplied by Albert M. Campbell, E. and E. M., of Charleston, West Virginia. The locality is 175 miles southwest of the area shown in figure 6.

which disappear in the strata under the Pittsburg coal bed, as well as pass out of sight in the strata immediately above that bed. Doubtless many other examples of these phenomena could be obtained, but apparently some clay-veins do not descend below the coal bed, or possibly, where invisible, they have suffered annihilation locally from enormous side pressure. Nor does it appear that they always run entirely through the coal, for some do not reach beyond the lower benches of the seam, while others seem to stop short at the base of the upper layers—that is,

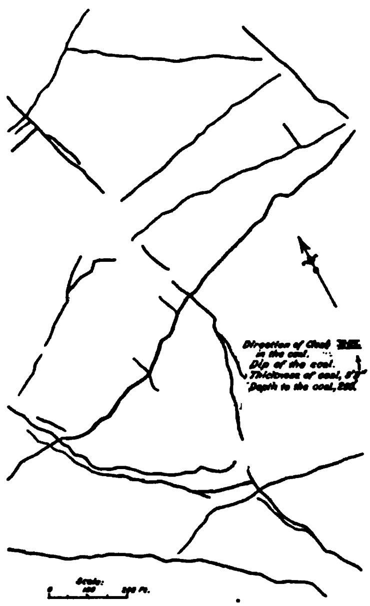


FIGURE 6.—*Plan of Clay-veins in the Pacific Mine.*

As surveyed in an area of about 31 acres of mine workings in the "Pittsburg" coal seam, Allegheny county, Pennsylvania.

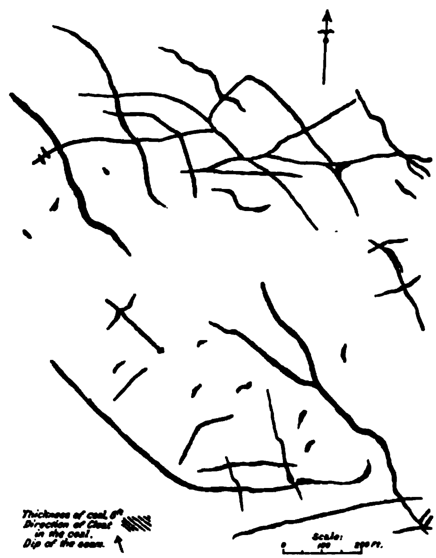


FIGURE 7.—*Plan of Part of most prominent Clay-veins in the Florence Mine.*

As proved by mining at depths between 150 and 300 feet in the Pittsburg coal bed, near Raymond, Putnam county, West Virginia.

about the middle of the seam. The veins often divide and reunite within the height of the coal bed. The crooked forms of the veins, together with the faulting of their walls, have produced nips or pinches, which cause the veins to appear to end where they do not.

PROXIMITY TO ONE ANOTHER

In the "Pittsburg" seam near Sewickley, in Westmoreland county, Pennsylvania, the writer counted five substantial clay-veins within a horizontal distance of 35 feet, whose aggregate width was about 42 inches. The masses of coal separated by these veins were more than usually tilted and twisted. Figures 6 and 7 give a good idea of the distance which may be driven or worked over in the Pittsburg seam without striking a clay-vein, or how many are likely to be encountered in a given area where they are plentiful. Mr Albert M. Campbell informed the writer that in the Kanawha region in West Virginia, where the Pittsburg seam, usually 6 feet thick, thins down to about half that height over detached areas of comparatively small extent, the latter contain numerous small clay-veins, while the higher coal between them is usually traversed by one or more extra thick clay-veins. In one mine he says, "We worked out 56 acres of coal clean by supporting the mountain on the clay-vein," because of their multiplicity. As yet we have no evidence that one clay-vein intersects another clay-vein, thus showing that one was formed before the other.

Faulting of Clay-veins and its Effects on the Vein Walls

As shown in figure 8, the coal seam is unusually disturbed by a clay-vein, the vertical displacement being about 6 feet. Here the vein is

Figure 8.—*Displacement of Coal Bed by Clay-vein.* One-seventieth natural size.

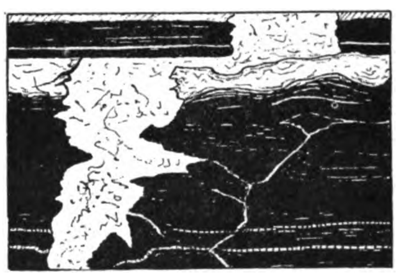


Figure 9.—*Disturbance of Coal Bed by Clay-vein.* One-fortieth natural size.

lying very flat, or rather seems to be passing from that position to a more vertical one, as traced upward through the roof coals.

The clay-vein illustrated in figure 9 exhibits a very different feature. In this case we have the coal bed merely torn through and the rent filled with clayey material, while the displacement, measuring about 3 feet, is lateral and belongs to the clay-vein, which here undergoes a sudden hitch or throw, the line of fracture occurring along the bottom of the roof-coal layers. Note also the crushed, distorted, and displaced coal layers on the right, intersected by vein-like forms of clay, admixtures of pyrites, etcetera. The maximum vertical displacement of the Pittsburg seam, or any other at or by a clay-vein, known to the writer, is 12 feet.

Such faults as these are very variable in horizontal extent, for they often die out in a very few yards or may be reversed in direction of throw in like distances, due to reversal of dip of vein.

"Horses" in the Vein Material

In many of the larger veins in the Pittsburg coal field fallen and tilted angular blocks of coal or of shale and coal mixed occur firmly embedded in the more clayey and fragmentary vein filling. One of these is shown in figure 1, page 37, others and smaller ones in figure 8, while figure 10 shows a very oddly twisted lump of coal, seen in contact with the foot-wall in the Pacific mine near Scott Haven, Pennsylvania. That some of these "horses" of coal may have belonged to the seams of coal opposite to which they occur in the clay-veins is likely, while others have probably dropped from seams higher in the series when the vein was open and in process of filling. These "horses" of coal invariably possess the characteristic cleat.

Figure 10.—*Piece of Vein-filling Coal.*

One-forty-fifth natural size.

"Spars"

Clay-veins less than 4 inches wide are called "spars." Figures 9 and 11 convey some idea of their forms and connection with clay-veins, the former being a vertical section, the latter (about 3 miles from the vein represented in figure 9) showing in plan six spars proceeding from one side of a clay-vein. On the opposite side of that vein no such processes were found. These narrow veins often injure the coal, and are more troublesome to the miner than the wider and more regular veins, but owing to their greater obscurity and irregularity but little attention is paid them by the mine surveyor.

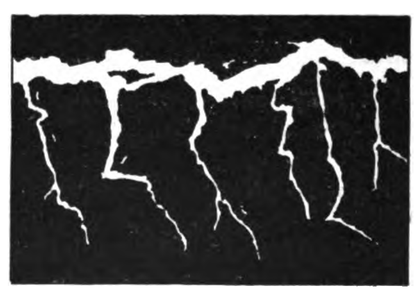


Figure 11.—"*Spars*" *in Coal.*

One-two hundred and fiftieth natural size.

The spars that connect directly with a clay-vein, as in figure 11, appear to have been open cracks made by twisting the vein walls at the time the clay-vein openings appeared.

Sandstone Veins and Veins of Sand

In a cannel mine in Beaver county, Pennsylvania, having a very strong roof of sandstone, probably about 120 feet thick, and where 1 foot of bituminous coal underlies the 8 or 9 feet of cannel, a nearly vertical vein of hard sandstone intersects the series. This vein varied from 2 to 6 inches in width, and in places contained considerable debris of cannel, with much pyrite and some limonite. Near Scott Haven, Pennsylvania, a vein of black sand is reported to have been struck in the Pittsburg coal bed many years ago. Mr C. R. Keyes, of the Geological Survey of Iowa, has reported the occurrence of compact sandstone walls in the coal near Des Moines.

Injected Vein Filling

Attention may be directed to a portion of a clay-vein represented in figure 12, where on the hanging wall of the vein is seen a streak of dark, hard, clayey material proceeding from the confluence of two thin strata of the same rock, which in the normal coal seam are separated by about 4 inches of coal. It is evident that here we have an excellent example of the way in which parts of the vein walls, having become softened by

Figure 12.—*Injected Vein Filling.*
One-fifteenth natural size.

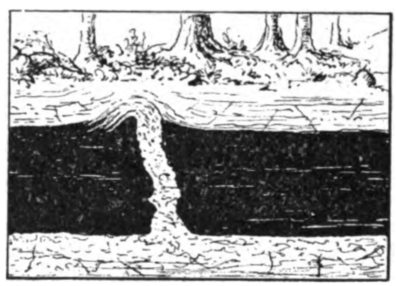


Figure 13.—*Flowage of Clay-vein.*
One-fiftieth natural size.

water in the fissure, flowed together by pressure into the fissure, and as a result of lateral squeeze, accompanied by a vertical drag or displacement of the walls, finally reached the stage or condition seen. Figure 13, copied from a photograph in the possession of Mr Leo Glück, formerly of the Geological Survey of Missouri, shows what seems to be a protuberance of the underclay of the coal bed through which it passes, which has been squeezed or caused to flow upward into an open crack. A singular feature of this clay-vein consists in the very curious overlap of the vein to the left on gaining the roof of the coal, where it would seem that the intrusive clay at this place met some obstruction, which diverted it and caused it to curl over and actually penetrate the upper layers of the coal bed in the manner shown.

Again, some of the sketches furnished by Mr Campbell, from his own careful observations in the Kanawha coal region, make it appear that the clay-veins penetrating the lower part of the seam only are injected or intrusive veins.

That many of the socalled "spars" were formed or filled with clay, sand, and other materials by mechanical force seems highly probable.

FOSSILIFEROUS VARIEGATED NODULES IN CLAY-VEINS

In a well defined and persistent clay-vein, at a depth of about 100 feet in the Pittsburg coal, at Buena Vista, Allegheny county, Pennsylvania, there occur some singular boulder-shaped, very hard masses of rock, two of which are shown in the middle of figure 14. The vein stuff at this horizon is composed of a mottled and variegated, closely compacted breccia of small rock fragments of sundry kinds, with a few larger lumps of coal in contact with the nodular masses. The appearance of this vein material suggests that it has undergone considerable mechanical and chemical alteration, as the component bits of rock are usually elongated, flattened, or drawn out, and have a rather run-together, viscous, or kneaded aspect. A fragment broken from one of these balls had a kind of shelly or easily spalled exterior, the flakes being about a third of an inch thick, while the interior of the nodule was very hard and compact, showing a few radial spar-filled cracks near the center.

FIGURE 14.—*Nodules in Clay-vein.* One-sixtieth natural size.

The composition of this nodule, both as to body and shelly exterior, is brecciated and variegated, and it shows evidence of chemical alteration, in that certain spots seem to have been converted into a reddish, streaky rock, while other areas reveal their original fragmentary structure much more plainly. The cementing and altered material seem to consist largely of silicate of alumina and lime, with irregular plays and crystalline nests of pyrite. Polished specimens of the shelly exterior of the nodule show that it contains a tendency to lamination in the arrangement of its more or less altered fragments, the larger and flatter edges or faces of these being approximately concentric with the surface of the nodule. Possibly this apparently quite local laminated or fibrous structure is referable to chemical alterations proceeding *pari passu* with mechanical and concretionary movements during solidification of the vein stuff.

Perhaps the most interesting thing about these nodules is that they contain remains of organisms. A polished portion of the rock revealed fragments of plants, as shown in figure 15. The three upper fossils are of black material, while the two lower forms are yellowish brown. in color. The latter may be seed cases, while those above appear to be terminals or bud-like extremities. Sir J. W. Dawson, to whom a drawing of the most perfect specimen was submitted, wrote that it was too small to determine. While the black streaks seen in other fract ures of the vein material in proximity to these nodules indicate the presence of more fossils, the writer has as yet been unable to find anything determinable.

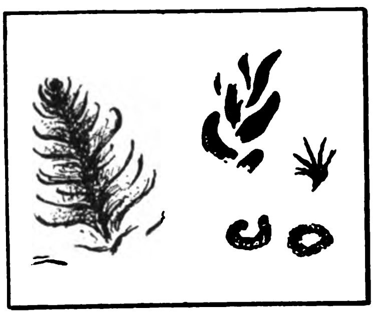


FIGURE 15.—*Fossils from Nodules in Clay-vein.* Magnified 5 times.

The plant fragments figured do not occur in any individual bits of rock in the matrix of the vein, but evidently got into position among the rock fragments as bits of dead or living plants that were washed or fell into the gaping fissure during the process of filling. They are remnants of the vegetation of the period in which the clay-veins were made.

OTHER CHARACTERISTICS

The clay-veins as proved and surveyed over about 2,000 acres of mine workings in the Pittsburg seam, about 27 miles south of Pittsburg, Pennsylvania, and bordering the Youghiogheny river, are observed to have no reference to or connection with (1) the dip of the coal field; (2) the axes of the anticlines and synclines or the "basins" running through the district; (3) the "cleat" of the coal; (4) the general trend of the "slack-veins" (these veins are referred to further on in this paper); (5) the local "swamps" or "hills" (depressions and elevations of the coal seams, irrespective of the main anticlines, etcetera); (6) the present topography, etcetera; (7) the general direction of surface drainage, and (8) the north line. An examination of the data as plotted in figure 16 will make this clearer to the reader.

Origin of the Vein Materials

The character and aspect of the finer clayey material, as also of the more fragmentary ingredients of clay-veins, are such as indicate that they were principally derived from the walls of the veins. If this were so, then these great cracks gaping upward remained open long enough to allow weathering and the gradual disintegration of their ragged sides, which bit by bit broke off and fell into the clefts, carrying down with them such additional bits of this or that stratum as they struck and dislodged. Probably running water from the rains helped in the filling process at times, and the action of frost may have assisted; also the presumed tendency of the walls to swell and come together would materially help to break up the beds and drop in the rock fragments. Probably wind-blown sand and plant remains, as we have seen, fell into the openings.

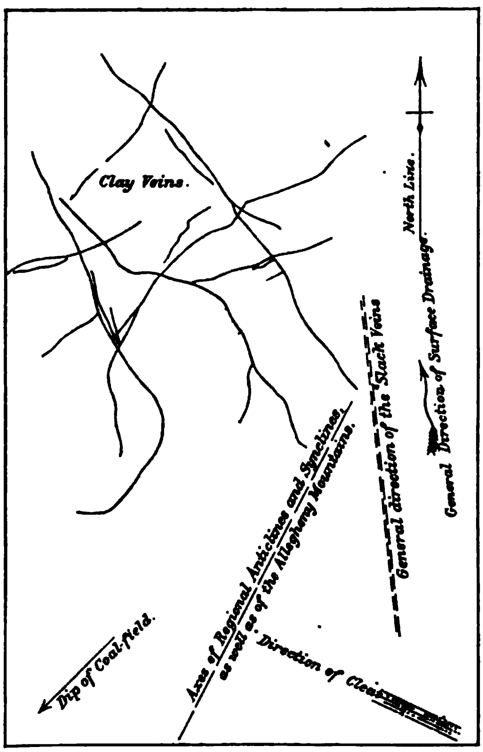


FIGURE 16.—*Diagram illustrating Trend of Clay-veins and their Relation to other physical Features.*

The derivation of the intrusively filled clay-veins has already been shown, namely, that they consist for the most part of underclays which have been softened and squeezed up into open cracks in the overlying coal, though the origin of the cracks is more obscure.

So far as we know, nothing has yet been found in a clay-vein except, perhaps, the little bits of vegetation above referred to, which can be said to be foreign to the Coal Measures; in most cases the vein stuff comes by descent from the walls.

"Slack-veins" or "Soot-veins" in the Coal Measures of western Pennsylvania

Of somewhat frequent occurrences in the southwestern part of the Pennsylvania (and perhaps in other seams as well), and brought to light by the mining of the Pittsburg coal seam, are reverse or overlap faults. These faults, while of comparatively small vertical throw, often extend for distances of several thousand feet across the mines. Figure 17 is a

Figure 17.—*Vertical Section in Mine at Buena Vista.*

One-sixtieth natural size.

vertical section showing the appearance of one of those overlaps in a mine at Buena Vista, Pennsylvania. This particular fault—a comparatively simple instance—has been repeatedly driven through and the coal removed from both sides of it for a mile and a half in the southerly direction in which it runs nearly straight from Buena Vista. These overlaps are called *slack-veins* or *soot-veins*, because the fault planes where they pass through the coal contain rather compact veins or seams of crushed and ground up coal sometimes several inches in thickness.

The veins of soot in this instance occupy the lines or planes between X X′ and A B in figure 17. The walls of these slack-veins are often highly slickensided. These slides or overlaps extend above as well as below the coal bed and in many cases they seem to spread or branch out laterally in the overlying rocks, especially in the roof coal and shales, over considerable areas. Where they pass through the latter strata very complex contortions and inversions may generally be seen in association with them. In some instances a slack-vein consists of a number of short and irregular fractures in the coal, accompanied by a complex system of small overlaps crumpling and twisting the coal. That the coal and its accompanying layers of shale often exist under considerable strain seems evident from the tendency of the tops or sides of the excavations, when in contact with them, to suddenly break down, as if getting relief from or expanding under the stress.

So far as the writer knows, these slack-veins are as liable to occur in one place as another in the Pittsburg coal field and at any depth; also that they pay no regard to the dip, swamps, clay-vein courses, cleavage of coal, or joints in the rocks, nor to the existing topography. It seems quite clear that the phenomena of the slack or soot veins in the fault planes, accompanied by the excessive rolling and folding of the clayey and shaly layers, suggest a slow or gradual faulting and not a sudden and violent break-up; and also that these faults being in a flat coal region are a product of lateral pressure.

A noticeable change in the dip of the coal takes place on approaching a slack vein.

"Horse-backs" in the Coal Measures of western Pennsylvania

Another kind of fault in the coal consists of local "rolls" or banks of hard, mottled clay, sandstone, and other material, which occupy either (1) the horizon of the lower layers of the seam or (2) areas where pockety masses of shale, etcetera, have replaced the roof coals and shale. It is claimed by some that clay-veins sometimes proceed from or have had their origin in these "horse-backs," as they are called. The two things are often in contact, and cases are known where clay-veins and horse-backs are so mixed as to be indistinguishable.

Age and Origin of the Clay-veins

A brief summary of the foregoing facts may be given before proceeding to discuss the subject theoretically. It has been pointed out—

(1) That these veins are filled, crooked and ragged, gaping fissures or rents in the Coal Measures.

(2) That the composition of the vein stuff is a compact and irregular and varying mixture of various sized (mostly quite small) rough bits of shale, limestone, sandstone, coal, etcetera, which cannot be distinguished from the composition strata of like materials, whose broken edges form the walls of the veins.

(3) That lateral pressure exerted by the vein-walls on the enclosed debris of rocks has been sufficient to produce considerable change in the form of the fragments, amounting in places to a structure not unlike fluxion, compelling the material to occupy less space than it originally did, creating shearing, faulting, and slickensiding in it, and the thrusting of the stuff into the joints and laminæ of the coal in contact with it, and producing various amounts of displacement and twisting of the beds on opposite sides of the vein.

(4) That the number, size, position, length, and arrangement of the veins seem independent of the dip of strata, depth of cover, cleavage of coal, existing configuration of surface, or other disturbances of the coal beds and of local basins or hills.

(5) Some portions of the coal fields contain them in greater numbers and dimensions than others, as also do some coal beds than others, and that but few, if any, coal seams are entirely exempt from them within the region described.

(6) That fragments of the vegetation of the period in which they were found became incorporated in the vein stuff.

(7) That metallic minerals have in places formed in and attacked the vein material, replacing portions of it and creating nodular and stringy ground of excessive hardness.

(8) That chemical and mechanical reactions have operated in places on the vein stuff sufficiently long and of such intensity as to convert it into nodular masses of rock in aspect resembling brecciated and variegated marble.

(9) That masses of coal embedded in the vein stuff contain the usual physical and structural features observable in the seams cut by the veins, which proves that such features are older than the clay-veins.

(10) That the slack-veins antedate the present topography and possess a trend having no regard to the courses and distances pursued by the clay-veins.

(11) That joined to, as well as mixed up with, the more prominent clay-veins are thinner and more meandering ones, which were evidently produced simultaneously with the stronger or leading veins.

(12) That all clay-veins did not reach up as far as the surface, some ending or being nipped in the floor or the roof of the coal bed.

(13) That the vein-stuff in rare instances was dragged or squeezed into the fissures from their walls or lower extremities.

That a clay-vein has the appearance of coming to an end, either vertically or laterally, in one place or another, is, of course, no proof that it does not in reality open out again farther on, a mere unseen crack connecting the areas of the vein.stuff.

Whether (*a*) the clay-veins in the highest coal bed, say, in southwest Pennsylvania, descend into the Pittsburg bed or even below it, or whether (*b*) those in the latter bed pass down through the "Barren" series and penetrate the coals, or (*c*) whether, on the other hand, the clay-veins in, say, the Kittanning coals, now by reason of elevation and erosion near the surface, originally extended up through the whole pile of the Coal Measures—in other words, are the roots, as it were, of the veins originally traversing the denuded Pittsburg coal—are questions of considerable geologic interest.

The questions *a* and *b* cannot be answered until the lower coals are mined vertically below the upper ones, and the clay-veins in both or all of the seams shall have been surveyed and mapped.

The Sewickley or Redstone coal, lying 60 to 80 feet above the Pittsburg bed, is very commonly reported to be much more seriously clay-veined than the latter; but the writer has failed to find any operator in it who keeps a plan of his mine, not to mention one of his clay-veins.

In the absence of proof to the contrary, it cannot be denied that during accumulation the Coal Measures may have been fissured and clay-veined more than once; and if so the question of their ages may eventually be determined by extended inspection and study of them. Could the period to which the fossil plant remains (see figure 15) belong be fixed, then something definite would be obtained. Possibly some day a flint arrowhead, a bone, or a shell may turn up in a clay-vein. Remembering that in various parts of the world fossiliferous fissures occur, whose ages (determined by the fossils) vary from the Permian to the Recent, it is evident a great range of time is allowed in which the western Appalachian and Interior coal measures may have been veined in this way.

As to how and why these gaping fissures came into existence the following suggestions are offered: The ragged and crooked forms of the veins leave no room for doubt that the strata were pulled apart laterally in such a way as to tear the rocks vertically in almost every direction (see figures 6 and 7, page 40); moreover, as the clay-veins exhibit no signs of having been formed at different periods, the inference is that such splitting open of the strata occurred at about one and the same time. It is possible that the fissuring was done suddenly, as fissures are produced by earthquakes today, but their reticulated appearance suggests a slower process of formation. Could shrinkage of the earth's crust have caused this peculiar breaking up of the strata into rude fissure-separated masses, somewhat after the manner of septarian formation, mud cracks, etcetera? Surface cracks in plaster, asphalt, concrete, and similar material often remind one, more or less, of plans of the clay-veins.

Irregular crustal elevation, accompanied by some torsional movement, might, perhaps, better explain the facts; or would a series of shifting or wave-like subsidences or depressions, on the sloping sides of which such fissuring might take place, suit the phenomena better?

Probably the character of the vein material implies that the tops of the fissures were above water when the strata opened. At any rate, no signs of a rush of water into them are known to the writer. The theory that clay-veins occupy deep and narrow channels cut out by running water has been advanced, but the appearances do not furnish any proof of this. Neither do clay-veins occupy previously existing faults, for if they did surely we should find traces of them. Again, is it likely that the fissures were formed when the great ice-cap retired northward, and are due to elevation of the affected area on the removal of the weight of the ice? Had their origin any connection with the formation of the series of basins or great rolls running parallel with the Allegheny uplift, the clay-veins would surely have a general trend in some particular direction, probably roughly parallel with the axis of these basins; but such is not the case.

It would seem, then, that until more facts are acquired the clay-vein fissures may at any rate be placed in the category of earthquake phenomena.

Age and Origin of the Slack-veins

Study of the phenomena has suggested the following theory as to the age and origin of the slack-veins: When the filling of the clay-vein fissures was completed the area embracing them was in the form of a flat and warped dome—that is, the surface was more convex than concave, and when a subsidence of this clay-veined territory took place, as the overlap faults and the slack veins seem to testify, enormous lateral pressure was put upon the clay-veins and produced the effects of compression in and in contact with them, as we have seen. When the clay-veins refused to suffer further squeeze, and the pressure not being exhausted, some other part of the strata had to give away; either folding would begin or fracture and displacement ensue, or both. What actually happened appears to be this: The harder strata broke obliquely across in the weakest places, and the beds sliding one on another, with the accompanying folding of the softer clays and other material, produced in course of time the veins of soot or slack as we have them today. Probably the amount of horizontal displacement in a slack-vein equals approximately the sum of the widths of the clay-veins, including spars, comprised in the area between the slack-vein—that is, supposing 200 inches equals the displacement at a slack-vein, the aggregate thickness of the several clay-veins between it and the next slack-vein will be about 200 inches.

The author regards clay-veins as not only the origin of slack-veins, but as having been largely instrumental in regulating the size, courses, and number of them in a given area, so that it would appear that if the slack-veins are younger, as they seem to be, than the clay-veins and the existing topography, and they bear no relation to one another, the clay-veins cannot possibly be very modern formations.

ALLIED PHENOMENA IN OTHER REGIONS

NOVA SCOTIA

Figure 18* is a plan showing numerous masses of shale encountered some 30 years ago in mining the "Block House" seam of coal at Cow bay,

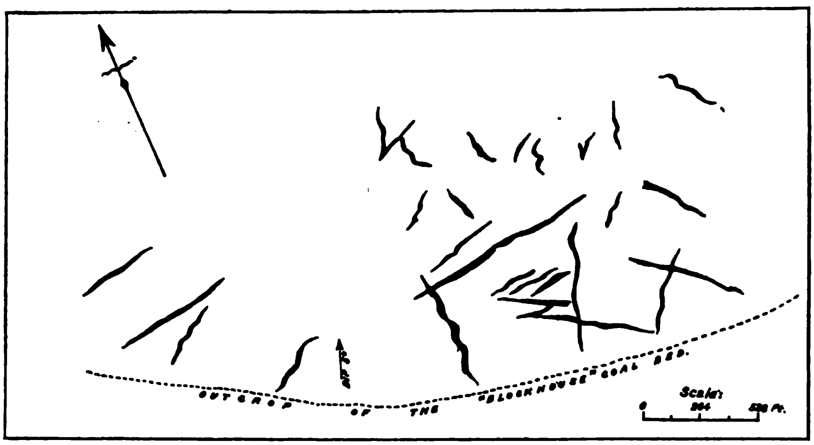


FIGURE 18.—*Plan of Shale Masses in "Block House Coal Seam.*

Cape Breton island, Nova Scotia. Figure 19 is a vertical section across a fair sample of one of these masses. A comparison should be made of figure 18 with figure 7 (page 40), which is a plan of part of the most prominent clay-veins in the Florence mine.

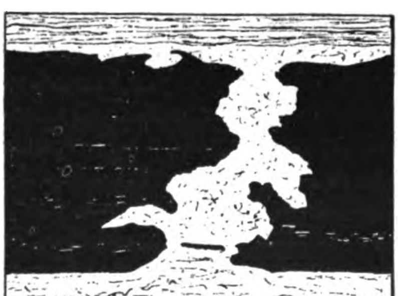


FIGURE 19.—*Vertical Section of Shale Masses in "Block House" Coal Seam.*

One-sixtieth natural size.

From Mr Rutherford's reference to these formations, it seems that in every case noted they did not extend beyond the coal bed and its roof. They probably owe their origin to currents of water channelling out the coaly material as soon as it had accumulated, which gaps or wants speedily became filled with

*Copied from Trans. Nova Scotia Inst. of Nat. Sci., 1868-'69, vol. 2, pl. 3, kindly furnished by Mr John Rutherford, M. E., of Stellarton, Nova Scotia.

the mud, which also sealed up the coal bed. Toward the dip these masses become fewer and smaller.

ENGLAND

Figure 20 illustrates a section in the "Main" coal at Moira, Leicestershire, England.

The plane or surface separating the two distinct masses of clayey material, filling the opening made in the coal, together with the reverse crumpling to which these intrusive masses have been subjected, points to the gash having been formed at two periods, the smaller and paler deposit indicating by its position that it is probably the older of the two.

FIGURE 20.—*Section in the "Main" Coal of Leicestershire, England.*

One-seventieth natural size.

The forked vein of clay shown in figure 21 was observed by the writer in the same seam as the last and about 3 miles distant from it. The only explanation seems to be that the coal was bent and opened a crack in its lower layers, into which the soft under clay swelled until the cracks were filled solid.

Figure 22 apparently illustrates a combination of the phenomena seen in the sections shown in figures 20 and 21, for here we have the coal bed

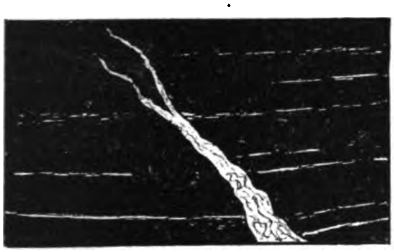


FIGURE 21.—*Forked Clay-vein.*

One-seventieth natural size.

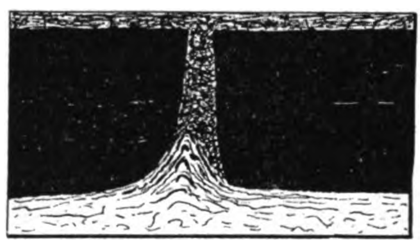


FIGURE 22.—*Combination Clay-vein.*

One twenty-fifth natural size.

cracked and pulled apart from top to bottom. The ultimate effect of this stretching was to allow the clay floor to swell and the darker overlying shale to be squeezed down into the opening. This section was observed at a depth of 1,075 feet and within 20 feet horizontally of a fault having a vertical throw of 250 feet. Possibly the pull upon the hanging wall of this fault which the curved and cracked strata suggest was the cause of the open break in the coal.

Figure 23 represents a section exposed in the workings of the "Little" coal at Donisthorpe, Derbyshire, at about 650 feet deep. In this case a tearing apart of the coal bed, accompanied by about 2½ feet of displacement, has taken place. When the rent was opened, the "horse" of shale, a fragment of the roof of the seam, fell in and came to rest on the under clay. Then the composed mass of rock debris filled up the rest of the opening to a height extending beyond the roof of the excavation.

FIGURE 23.—*Section of Clay-vein in the "Little" Coal of Derbyshire.*

One-fiftieth natural size.

Figure 24 illustrates a section exposed in a tunnel or drift at Moira, in Leicestershire, at a depth of about 1,050 feet, at a point where a fault of 240 feet throw was crossed. From wall to wall the fault filling was about 20 feet wide, and carried, near its middle, a large horse-like mass of coal 3 feet thick. The rest of the material consisted of angular and crushed fragments of a variety of Coal Measure strata, more or less cemented together with pyrite, calcite, quartz, etcetera. The character of the contents of this deposit make it evident that the fault originally existed in the form of a huge gaping rent in the Coal Measures, which remained open long enough to become filled in the manner shown. The same fault was crossed about 1½ miles to the northeast of this section in a railway cut. Its width there was 12 feet, and angular blocks of coal formed part of the more clayey filling.

FIGURE 24.—*Section in a Tunnel at Moira, Leicestershire.*

One-hundredth natural size.

Figure 25 represents a vertical section revealing a remarkably flat vein of clay, X X′, intersecting the "Lount Middle" coal bed at Coleorton, Leicestershire, at 550 feet deep. On the left of the figure the coal had been removed by a washout about 300 feet in width. Details of the section render a lengthy description unnecessary.

NEW ZEALAND

Figure 26 is a copy of a sketch made in 1879 by Mr G. J. Binns, government mine inspector, of a section of a vein of "pure white unctuous

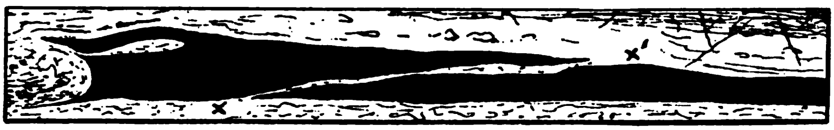


FIGURE 25.—*Vertical Section in the "Lount Middle" Coal Bed of Leicestershire.*
One-fiftieth natural size.

clay," hardly solidified, which intersected a 4 foot 9 inch seam of coal in the Springfield colliery, Canterbury, New Zealand. The roof of the coal bed was "very flaky and hard." The shape of this vein of clay, while peculiar, suggests a filled up crack or fissure.

FIGURE 26.—*Section of Clay-vein in Springfield Colliery.*
One-twentieth natural size.

UNITED STATES

Figure 27 represents a section noted by the writer in 1894 near Beaver Falls, Pennsylvania, in the Lower Productive Coal series. A clay-vein is here observed cutting a swell or "horse-back" occupying the horizon of a one-inch shaly parting separating the bed of coal seen in its normal condition on the right. From the phenomena presented it does not seem that the clay-vein had anything to do with the origin of the "horse-back,"

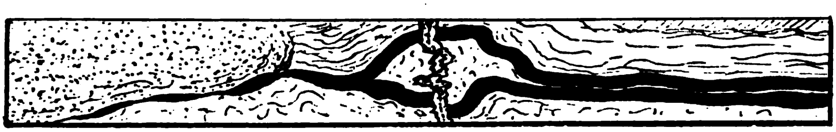


FIGURE 27.—*Section of Clay-vein near Beaver Falls.*
One-fiftieth natural size.

but it appears that the mass of sandstone seen on the left occupies a partially eroded area and has been pushed toward the right, squeezing what was left of the coal into rolls beneath it and creating the opening between the two layers of coal into which crept the clay forming the "horse-back." Of course the clay-vein is the newest deposit in this section.

Figures 25 and 27 are interesting examples of contemporaneous erosion and deposition in the coal period, and may serve to remind those who spend much time underground of numerous other instances of somewhat similar phenomena, and of which mental note or sketch-book record was made.

Though somewhat irrelevant in this connection there are two facts pertaining to the clay-veins in Pennsylvania which should be noted if only as a matter of record: In newly developed mining territory the cutting of one of these veins for the first time will sometimes draw off the water in surface springs overhead—a circumstance which makes it evident that *some* of the clay-veins *do* extend to the soil above. Again, the coal next above the Pittsburg bed, being full of clay-veins, confines the explosive gas in it, which, as many claim, issues in considerable quantities into the workings of the coal below as the withdrawal of the pillars proceeds.

Concluding Observations

Notwithstanding there must be a large amount of data on clay-veins of which the writer is ignorant, he still has reason to think that, with a little more attention paid to them by mine surveyors and engineers of mines, much valuable material might in course of time be recorded.*

In view of the fact that none of these deposits possess commercial value, it may be and indeed has been urged that from the standpoint of practical or economical considerations there is not very much to be derived from such study, but the true investigator is justified in declining to give too much weight to such arguments and in insisting that wherever and whenever an opportunity to examine exposures of these veins presents itself, every advantage ought to be taken of it, for no two clay-veins are exactly alike; one always finds physical, structural, and material differences, and all of them have their meaning, the explanation of which can only become clearer and more satisfactory by extended survey, scrutiny, and methodical collecting and arranging of facts. It is only by such methods that whatever material significance they may possess can be revealed.

Reverting to the question of the origin of these veins, it has often occurred to the author when turning over the plans of metalliferous veins

* For valuable information in this connection sincere thanks are hereby accorded to Albert M. Campbell, John Rutherford, A. N. Humphreys, F. T. Hogg, Selwyn Taylor, George J. Binns, and others.

that accompany geological and mining reports and papers, that certain of them or portions of them would serve very well for plans of clay-veins, such as figures 6 and 7 (page 40) of this paper, but want of time forbids a reperusal of the mining literature in which such plans appear in order to give the references. The thought which occurred to me in this connection is that it may be possible that the same causes which produced the fissuring of the Coal Measures may also have been the origin of some of the well known fissure veins of metalliferous mining regions. The author conceives that during geological time there may have been many periods at which a rending of the strata, such as that which happened to the Coal Measures and gave birth to the clay-veins, may have occurred in one region or another, and to such fissuring probably some of the phenomena to which book references are given at the close of this paper is attributable.

The foregoing suggestion, subject, of course, to verification, is offered in the hope that it may prove of value in future investigations.

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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 9, PP. 59-84 JANUARY 24, 1898

ORIGIN OF THE GORGE OF THE WHIRLPOOL RAPIDS AT NIAGARA

BY FRANK BURSLEY TAYLOR

(*Read before the Society August 10, 1897*)

CONTENTS

INTRODUCTION

Since the retreat of the last ice-sheet and since the waters of glacial lake Warren were drained off through the Mohawk valley, the Niagara river has cut out a great canyon from Lewiston to the Horseshoe fall, 6½ miles long, mostly over 300 feet deep, and more than 1,000 feet wide. When studied in detail it soon becomes apparent that nearly all of the gorge has been made by a great cataract, in volume substantially like the present falls; but there are two or three parts that obviously demand some other explanation. One of these is the comparatively narrow and shallow gorge of the Whirlpool rapids, the origin of which it is the particular object of this paper to discuss.

There are two distinct classes of facts which contribute to the unraveling of the gorge history. One is derived from the study of the characters of the gorge itself, the other from the study of the history of the upper Great lakes, which are the reservoirs whence the cataract has drawn its power. In the interpretation of the gorge by its own characters large use will be made of the comparative method. By taking as the standard of comparison some part of the gorge concerning the origin of which there is the highest degree of certainty and comparing other parts with it, due allowance always being made for all observable causes of difference in the gorge characters and for all evidences of difference in age, the main episodes and critical points of the gorge history ought to be disclosed. Then by turning to the lake history and noting the changes of outlet, if any occurred, and noting the order of such changes, we are prepared to anticipate the presence and order of gorge characters corresponding to the changes of volume which the river would undergo in consequence of changes of outlet in the upper lakes. Thus by the correlation of causal factors with resulting characters we may finally reach the true history of the gorge.

Whether or not this very desirable end is open to our attainment today depends mainly on the fullness of our present knowledge. Investigation has progressed rapidly and a great mass of facts have been gathered by those interested in the subject. Practically all the shores of the Great lakes have been explored, not exhaustively in all cases, but with sufficient thoroughness to bring out clearly the larger factors of their history, and it is believed that no event of great importance or critical bearing has been omitted. The gorge too has been studied with much care, and the correlations which have been made out between the two sets of phenomena appear to be remarkably close and complete, leaving nothing of importance unaccounted for on either side.

In discussing the origin of the gorge of the Whirlpool rapids it is necessary, for the sake of clearness, to give some attention to other sections above and below; hence the present discussion and the accompanying map cover somewhat more than half the length of the gorge, or from the

Horseshoe fall down to the upper side of Wintergreen flat. The map,* figure 1, shows the varying width of the gorge, and this, taken in connection with varying depth, constitutes the main reliance for interpretation.

Description of Gorge Characters

GEOLOGICAL CONDITIONS

The geological conditions at Niagara have already been so fully described by Hall† and Spencer‡ that it seems unnecessary to repeat the description here. The strata as a whole lie in a position almost horizontal; so nearly so in the part of the gorge here considered that the very gentle southward dip may be neglected. The most important circumstance, and the one which gives the falls their peculiar character, is the arrangement of the strata—a thick, hard layer above with a thick soft layer below. This arrangement keeps the falls constantly vertical with a deep hole at their base. The recession of the falls and hence the making of the gorge are accomplished mainly by the cutting away of the soft beds in the bottom and sides of the hole. In this way the thick, hard bed of limestone above is undermined and falls piece by piece into the hole below, where the great blocks are spun round and round by the powerful currents and slowly grind away the softer shale.

UPPER GREAT GORGE

Beginning at the Horseshoe fall, let us note the chief characters of the gorge as we go down the river.§ Opposite the extreme west end of Goat island and just in front of the Horseshoe fall the top width of the gorge is about 1,250 feet. Thence it gradually widens to a point opposite the center of the American fall, where it is about 1,700 feet wide. A little

* The accompanying map, figure 1, was reduced from a tracing of the "Niagara Falls" sheet of the U. S. Lake Survey (1875). The Survey chart has been followed closely, except for the vicinity of the Whirlpool basin, where the later survey of Mr G. K. Gilbert has been followed ("Niagara Falls and their History." National Geographic Monographs, 1895, page 231). The heavy lines mark the upper edges of the cliffs on the two sides of the gorge; the lighter lines the present water margin of the river, and the dotted lines in the vicinity of the Whirlpool the bluff edges of the eroded drift-filling of the old Saint Davids gorge. Hachures indicate rapids or turbulent water. The arrows in the Whirlpool and the smaller basin next above show return or backward currents. The places where critical events of gorge history occurred are known with only approximate accuracy, say within a few rods either way from the transverse lines by which they are represented on the map.

† James Hall: "Niagara falls, its past, present, and prospective condition." Nat. Hist. of New York, Geology, part iv, chap. xx, 1843, p. 386.

‡ J. W. Spencer: "The duration of Niagara falls." Am. Jour. Sci., iii, vol. xlviii, Dec. 1894, pp. 457–458.

§ The Niagara chart of the U. S. Lake Survey is taken as the basis for all measurements of width and length. While it may not be entirely free from errors, as has been found to be the case for the topography at the Whirlpool on the Canadian side, it is, nevertheless, no doubt, substantially accurate and is the best authority at hand.

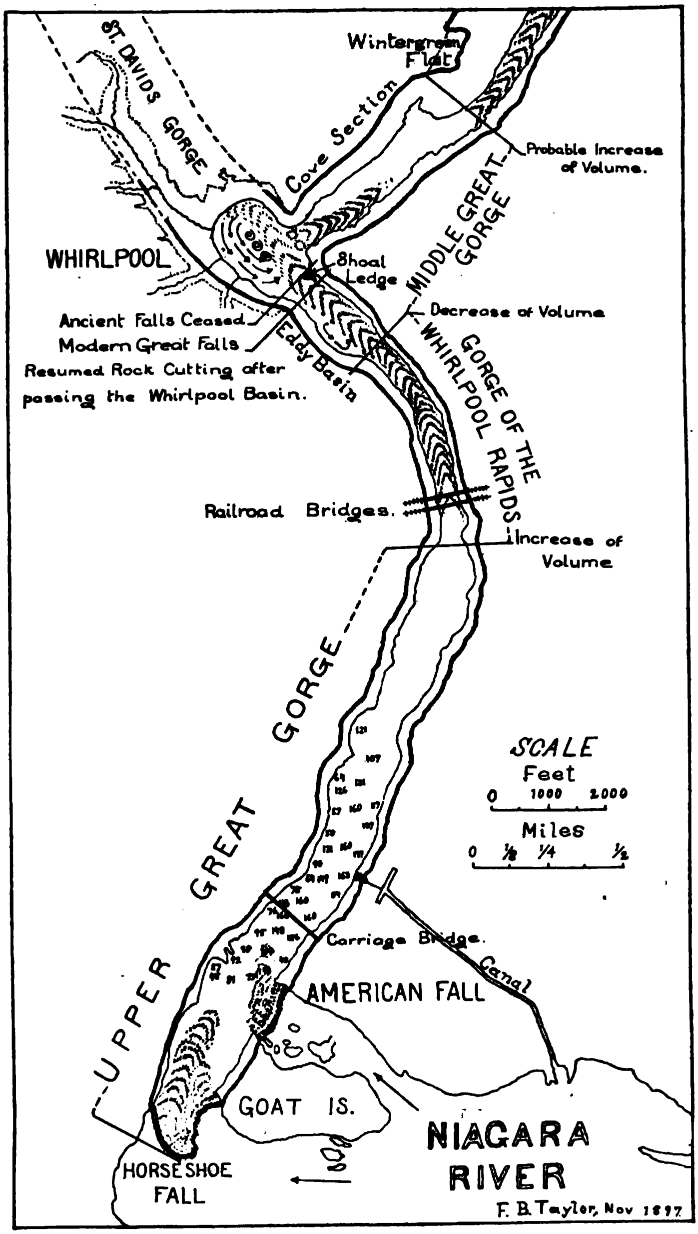

FIGURE 1.—*Map of the Gorge of Niagara from the Falls to Wintergreen Flat.*

below the American fall and just opposite the inclined railway it is about 1,350 feet, and in midstream, where the deepest sounding in the river is found, it is 189 feet deep. Thence, for about a mile and a half or nearly down to the railroad bridges, the width varies between about 1,350 and a little more than 1,000 feet, the narrowest point being midway between the carriage and railroad bridges. At a point 35 or 40 rods above the upper railroad bridge the gorge suddenly grows narrow and shallow, and this is the beginning or head of the gorge of the Whirlpool rapids. The distance from the Horseshoe fall down to this place is about 2½ miles. Throughout this section the dimensions of the gorge are remarkably uniform, except in that part which lies opposite Goat island and the American fall, but the increased width here is not more than may be readily accounted for by the widening of the river bed above the falls when the cataract was passing this part of the gorge. It seems quite certain that whenever the falls grew wider than usual and the water in consequence poured over the brink in a thinner sheet, then the power of the falls to excavate in the hole below was reduced. We should expect, therefore, to find the expanded parts of the gorge generally shallower than the parts of average width. So far as the scanty soundings go, they seem to support this expectation. It appears to be quite certain, therefore, that the slight expansion of the gorge near the falls is not an indication of increased volume, but only of increased width of the river bed above the falls. There is apparently nothing in the section above the gorge of the Whirlpool rapids which suggests variation of volume. This is, of course, the most recently made section, and it has evidently been made solely by the action of the great cataract with substantially the same volume as now. Inasmuch as there are other parts of the gorge farther down that have substantially the same dimensions, it seems appropriate to call this section the Upper Great gorge. On account of its newness and the greater degree of certainty concerning the conditions attending its excavation, this section will be taken as the standard of comparison for the rest of the gorge.

GORGE OF THE WHIRLPOOL RAPIDS

Next below the Upper Great gorge is the gorge of the Whirlpool rapids three-fourths of a mile long. Its top width throughout most of its length is close to 750 feet, with a minimum of a little over 700 feet and a maximum of about 950 feet. This greatest width, however, is confined to one point near the head of the section. The section as a whole is very even from end to end. There are no soundings in this part of the gorge, but by the careful application of a very simple method Mr G. K. Gilbert has made a close estimate of its depth and places it at about 35 feet.* The narrowness and shallowness of this section are quite striking in comparison with the Upper Great gorge and with some other sections lower down.

EDDY BASIN

The gorge of the Whirlpool rapids ends abruptly at the north at a point about 100 rods above the south side of the Whirlpool. At this place the gorge suddenly expands to a width of about 1,200 feet and appears to be quite deep. The tempestuous waters of the rapids above issue from the mouth of the narrow gorge with such high velocity that their momentum carries them clear across the short deep section and into the Whirlpool before they lose their ruffled aspect. The greater part of the expansion of this section is toward the west side, so that as the current rushes out of the gorge of the rapids above it crosses not exactly in the center, but toward the east side of the basin, leaving the water of the west side comparatively undisturbed. On that side a slow return current sets back toward the south, forming a large but gentle eddy. The current is of great volume, but it moves very slowly, and the manner of its motion suggests great depth. The best point from which to see the action of the water in this section is from the top of the gorge on the west side, where a projecting point affords a view over the eddy to the eastward and over the Whirlpool to the north.

It is very desirable—indeed almost indispensable—to have some distinguishing name for this short, deep section of the gorge. The best name that has suggested itself to the writer is derived from what is perhaps the most characteristic feature of the section, the large eddy. For the purposes of this paper, therefore, this section may be called the Eddy basin. The Whirlpool is sometimes spoken of as an eddy, and possibly it is properly so classed; but if it is an eddy, it is one of a peculiar kind, for the river in the Whirlpool makes a great loop, turning from a northerly direction toward the west and then back to the south, passing out to the east by descending and going under the entering current. This curious figure of an underdoubled loop is performed by almost the entire volume of the river. In the Eddy basin, on the other hand, the current forms a side whirl or eddy of the common type, involving only a small fraction of the whole stream. The Eddy bears no comparison to the Whirlpool as a scenic feature of the river, but it is a convenient mark of distinction for this section. The name "Whirlpool" has become inseparably attached to the great loop, and it is seldom spoken of by any other. There appears to be no bar, therefore, to the use of the name "Eddy" for the

*G. K. Gilbert: "Profile of the bed of the Niagara in its gorge." (Abstract.) Am. Geologist, vol. xviii, Oct., 1896, p. 232.

side whirl in the basin next above, nor for the use of the names " Eddy basin " and Whirlpool basin " for these two parts of the gorge.

In passing from the Eddy basin to the Whirlpool there is a slight contraction of the gorge, the top width narrowing from about 1,200 to 1,000 feet, while the width at the water line narrows from about 850 to 550 feet. At the place of greatest contraction there is a ledge of rocks projecting from the east bank directly out into the swift current 50 feet or more and covered by only a few feet of water.* In low seasons and when the water is clear it is plainly visible. Besides this visible ledge, the behavior of the water indicates a shoal spanning the river in the contracted part.

WHIRLPOOL BASIN

Next below the shoal ledge is the Whirlpool. So far as the postglacial or modern river is concerned, the history of this part of the gorge is very simple. The Whirlpool basin is part of the old Saint Davids gorge, which extends northwestward to the village of Saint Davids, where it opens out with a wide mouth at the line of the escarpment. This old gorge is now filled with drift, and the modern river had only to wash out the part now occupied by the Whirlpool when it had cut back this far. Where the western wall of the old gorge is exposed, in Bowmans ravine north of the Whirlpool, it is found to be smoothed and scored by glacial action, and bears striæ even as far down as the Clinton limestone. These circumstances prove beyond a doubt that this section is of preglacial or interglacial age. It also appears to have great depth. Considering the kind of action that goes on in the Whirlpool, it seems hard to think of it as being much less than 200 feet deep.

COVE SECTION

At the lower side of the Whirlpool, where the water passes out, there is a much sharper contraction than that noted above. The top width for a few rods is only about 900 feet, the narrowest point anywhere outside of the gorge of the Whirlpool rapids, and the width at the water line is about 450 feet. The river is shallow at this place, and the sharp descent of the short rapids seems to show that it falls over a shoal ledge spanning the river from side to side. Below this the gorge widens and deepens. For most of this section, which for convenience we may call the Cove section, the top width is nearly 1,300 feet, but just above Wintergreen flat it broadens to 1,600 feet.† After passing the shoal at

* This ledge was pointed out to the writer by Mr Gilbert in August, 1896.

† By a glance at the map, figure 1, page 62, it will be seen that there is a small cove running northward from the northeast end of the wide, deep section which lies between the Whirlpool and Wintergreen flat. This is probably the most quiet piece of water to be found on the river between the falls and Lewiston, and it seems to furnish an appropriate name for this section.

its head this section is an almost placid pool. apparently of great depth.

Schemes of Interpretation

GENERAL STATEMENT AS TO HYPOTHESES OF ORIGIN

We have now before us a brief description of the principal characters of the gorge from the Horseshoe fall down to Wintergreen flat. Except in the case of the Upper Great gorge, it has been the purpose of the writer to set forth the facts as far as possible without any coloring from theories of interpretation. To this end nothing has been said as yet about the particular conditions that obtained during the making of any of the lower sections.

The conditions which prevailed during the making of the Upper Great gorge are so manifest that they were given above when the characters of that section were described. The whole of the section appears to have been made by the great cataract at substantially the same volume as now and without material variation; and to this interpretation there seems to be no alternative nor any ground for exception, but for the gorge of the Whirlpool rapids, the Eddy basin, and the Whirlpool basin more than one explanation has been suggested. With regard to the Eddy basin, however, the writer is not aware that any one has noted a genetic distinction between it and the contiguous sections above and below. Whether in the minds of students of Niagara this short section has hitherto been regarded as a part of the gorge of the Whirlpool rapids, or as a part of the Saint Davids gorge, or as a genetically independent section, does not appear with entire certainty. In the view of the writer it is independent and belongs with the Cove section. Its characters seem quite clear as to its own origin, and if they are here correctly interpreted it then becomes a decisive factor in the interpretation of the gorge of the Whirlpool rapids; but these relations will be discussed more fully below.

One of two principal hypotheses has generally been assumed as the basis of explanation for the making of these parts of the gorge. In accordance with one, it is assumed that the whole gorge, excepting always the Whirlpool basin, has been made by the modern or postglacial river Niagara, and that the varying magnitude of the gorge in different sections is due to variations of volume. In accordance with the other, not only the Whirlpool basin, but the gorge of the Whirlpool rapids, including the Eddy basin, are supposed to have been made by a small stream, and therefore to be mainly of preglacial age, and to have been merely cleared of drift, with perhaps a little deepening and widening by the modern river. The latter of these hypotheses has appeared in several modified forms.* The first one seems to be the simpler. Let us apply it and note the river history which it suggests.

INTERPRETATION ON THE BASIS OF VARYING VOLUME

Cove section.—The origin of the gorge characters may be considered best in the order in which they were made. First, then, as to the Cove section. What volume is indicated by its characters, and how does it compare with the Upper Great gorge? Its prevailing top width is close to 1,300 feet, and it is a deep, placid pool. This corresponds almost exactly with the lower two-thirds of the Upper Great gorge. The geological conditions in the two sections are so closely identical that there is no reason to expect appreciable differences of gorge characters from their influence. Hence it seems a plain inference that, since all the other conditions are substantially the same, and since the gorges produced are of the same magnitude, the volumes of the two cataracts must have been substantially the same in the two cases. The widest and narrowest parts in the two sections are also closely alike—1,600 and 900 feet in the lower section and 1,700 and 1,000 feet in the upper. The width at the water surface is noticeably less in the lower section, but there is good reason for this difference. The hard bed of the gray quartzose sandstone (Medina), more than 20 feet thick, forms a projecting shelf on which the talus of the beds above rests, and its edge forms a low cliff. In the lower section this layer is a few feet above the water, while in the Upper Great gorge it is 40 to 50 feet below the surface. If the lower section were filled with water up to the same height above the quartzose sandstone, the width at the water surface would be about like that in the Upper Great gorge. In fact, the parity of characters in these two widely separated sections is as perfect as one could expect if it were certainly known that they were made by cataracts of exactly the same volume.

Whirlpool basin.—As the falls cut their way back from Wintergreen flat there finally came a time when there remained only a thin high wall of rock between the drift-filled Saint Davids gorge and the upper end of the newly made Cove section. This frail partition finally began to break down, and there was, of course, a coincident lowering of the water surface over the Whirlpool; but even before the partition began to crumble the water above probably took on a rapid, agitated motion and began to wash out the drift. The falling of the river and the washing out of the drift must have followed the lowering of the wall nearly simultaneously, and, considering the softness of the drift-filling, this process must have

* In one form or another this view is held by Pohlman, Wright, Upham, Winchell, Claypole, Tarr, Spencer, and others.

been propagated up stream rapidly to the first resisting ledge of rocks in the path of the river, and this took place at each step in the progress of the lowering. A bank of drift could not endure more than a few minutes, or, at most, a few hours, with so great a volume of water pouring over it as a cataract or rushing over it with the fury of the rapids. It follows that with the lowering of the thin wall there came into existence almost simultaneously a new cataract at some point higher up. As the wall broke down and the water above fell the new cataract grew in height. At first it was low, a mere swell, then a cascade, and finally a cataract. As soon as it had developed sufficient force by the power of its fall it began gorge-making on its own account.

At the place of the crumbling wall below an opposite change went on simultaneously. With the gradual lowering of the wall this cataract lost its power and stopped, or, at least, greatly diminished its work of undercutting. This virtually stopped its recession, and the wall was henceforth removed mainly by wearing and breaking off at the top—a slower process—and the lower the wall became the more slowly it wore away. While the thin wall was wearing down the new cataract was retreating, cutting slowly and not deeply at first, because it fell only a few feet, but with the lowering of the water at its foot it gained power and gradually took on the character of the great cataract that had cut out the Cove section. The cutting away of the thin wall at the lower side of the Whirlpool must have been effectually checked when the hard bed of the quartzose sandstone was reached. This layer probably formed for a long time the sill over which the water made a moderate cascade, but at length it was broken through. The foundation of the thin wall is still there, and it is over this that the river makes its sharp, swift descent just below the Whirlpool.

Upper Shoal ledge.—When it encountered the drift-filled Saint Davids gorge the cataract was shifted with relative suddenness from the Cove section to some point above the Whirlpool substantially in the manner described above. Where was the new cataract? Did the old Saint Davids gorge end at the south side of the Whirlpool or did it extend up to the south side of the Eddy basin; or did a small creek ravine extend still farther up, where the gorge of the Whirlpool rapids is now, to the lower end of the Upper Great gorge?

This brings us to the most important and critical point in the Niagara problem, so far as it can be interpreted from the study of gorge characters alone. The solution of the problem of the origin of the gorge of the Whirlpool rapids depends mainly on the answer to the question, What is the age of the Eddy basin? If this basin is a part of the preglacial Saint Davids gorge, then, so far as can be inferred from the study of the gorge characters alone, the gorge of the Whirlpool rapids may well be an old preglacial creek ravine; but if the Eddy basin is of postglacial age, then the gorge of the Whirlpool rapids must also be of the same age, and must have been made by a cataract of much less volume than those which made the greater sections above and below it.

We have seen that there is a slight contraction and a shoal ledge between the Whirlpool and the Eddy basin. Their position and character are substantially what would be expected if this were the site of the new cataract which began work while the basin of the Whirlpool was having its loose drift washed out. As pointed out above, the new cataract began as a feeble fall of slight descent. Hence, at first it did not bore deeply at its base, but as it grew in height by lowering the water in the Whirlpool, it bored deeper and deeper, while at the same time it was slowly receding. It seems probable that the upper shoal ledge and the contraction stand for the time of the feeble falls, and that by the time the cataract had attained sufficient height and power to bore deeply at its base it had receded so far that it no longer fell on the ledge, but back of it to the south, where it began to bore the deep hole of the Eddy basin.

Two other factors may have contributed to the making of the upper shoal ledge. If the great preglacial or interglacial cataract that made the Saint Davids gorge stopped its work suddenly at the south side of the Whirlpool basin, as it seems to have done, and if the overhanging ledge thus abandoned stood for any considerable time exposed to the weather before the last ice-sheet came upon it, then cliff recession by weathering must have taken place just as it has in all other parts of the gorge. The vertical face of the shales below would crumble away and the overhanging ledges of limestone would fall off, covering the face of the shales with a talus of fragments. This cause alone would probably have left the shoal ledge where it is now found, for the new cataract would not begin where the old one left off, but at some point several rods farther back—as much farther back as the cliff had receded by weathering. Then, too, the process of glaciation which smoothed and scored the west wall of Saint Davids gorge below the Whirlpool may have worn or torn away some part of the old cliff where the former cataract had been, and this, so far as effective, would also set the beginning place of the new falls farther back. All three of these factors may have contributed to the making, or rather the leaving, of the shoal ledge between the Whirlpool and the Eddy basin.

Middle Great gorge.—It was pointed out above that the Eddy basin is apparently deep, and that it has a top width of about 1,200 feet. This is a trifle less than the width of the middle part of the Cove section, but it is the same as that of the Upper Great gorge opposite the end of the old hydraulic canal (about a quarter of a mile below the carriage bridge), where the soundings show a depth of over 160 feet. In the lower two-thirds of the Upper Great gorge the extremes of top width are about 1,000 and 1,300 feet, so that the top width of 1,200 feet for the Eddy basin is not far from the mean of that section. From such a comparison it seems probable that the Eddy basin was made by the great cataract with the same volume as it had in the Cove section, and the same as it has now. While this correspondence of magnitudes does not prove identity of origin absolutely, it is nevertheless true that there is apparently no fact or circumstance which can be offered in disproof of it. The Whirlpool basin itself indicates nothing as to the volume of the modern river at the time the drift was cleared out. Unless we suppose a sudden change of volume to have occurred just then, we should look for the reappearance of gorge characters like those of the Cove section at some point above the Whirlpool—wherever the new cataract resumed work. The Eddy basin has these characters, and it seems natural, therefore, to associate it with the Cove section, putting the two together as one continuous piece of work, interrupted and separated only by the comparatively brief incident of the Whirlpool washout. These two sections taken as a unit may be called, provisionally, the Middle Great gorge.

One other circumstance seems to lend strong support to this interpretation of the Eddy basin. This basin is a deep hole to the south of or behind the shoal ledge which lies between it and the Whirlpool, and was made after the ledge had been passed. With such width, and with the great or very considerable depth that it appears to have, it seems well nigh certain that it was made by a large cataract. In that case it must belong either with the Saint Davids preglacial gorge, supposing this to have been made by a great cataract, or else with the Cove section of the modern gorge. It can hardly be attributed to a small stream in any event, because a small stream would not have bored out so large and deep a hole behind the ledge. A small cataract falling into a deep pool of water has little or no power to excavate at its bottom, and it seems plain, therefore, that a small stream would not have made a hole so wide and deep as the Eddy basin. Thus, whatever its age, it is in all probability the work of a great and not of a small cataract. This greatly increases the probability that it is of modern origin, for if it is preglacial and a part of the Saint Davids gorge, why should the shoal ledge be there? Some special explanation will have to be invented for the ledge and the associated contraction of width if this view is to be maintained.

Eddy basin and the gorge of the Whirlpool rapids.—If it be granted that the Eddy basin was made by the modern great cataract, then there follows very closely another important conclusion, namely, that the gorge of the Whirlpool rapids was cut out entire by a postglacial stream of relatively small volume and is not the site of a preglacial creek gorge, as is supposed by many, and this for the following reasons: The element of time is a very important factor in gorge-making, especially where the circumstances are like those at Niagara. If it were not for the fact that the upper hard ledge of limestone resists disintegration stubbornly and endures for a long time as an overhanging ledge before it breaks down, the cataract would not have time to bore out a deep hole at any place; but there appears to have been time enough for deep boring in the making of the Eddy basin, thus demonstrating the solidity and compactness of the capping layer of limestone, and this in turn appears to leave us no other alternative than to suppose that the gorge of the Whirlpool rapids is of postglacial age, provided we assume that the Eddy basin is postglacial also. If it should appear, however, that the Eddy basin is preglacial, then it is granted that it may be true, so far as can be deduced from the study of gorge characters alone, that the gorge of the Whirlpool rapids was originally a drift-filled creek gorge of preglacial age. Even then, however, the explanation would not be by any means so simple as some have assumed, for it would still be necessary to suppose the Eddy basin to have been made by a stream of large volume and the gorge of the Whirlpool rapids by one of much smaller volume. Hence, while the dimensions of the Eddy basin appear to accord better with the Cove section and the Upper Great gorge than with the Saint Davids gorge; while the presence of the shoal ledge seems to indicate a difference of age, and while the glaciation of the Saint Davids gorge seems to be absent from the Eddy basin, none of these evidences, nor all of them put together, make a sure case for the postglacial age of this section. The age of the Eddy basin, therefore, so far as it can be deduced from the study of gorge characters alone, remains a matter of some doubt, but with an apparent preponderance of evidence inclining to the conclusion that it is of postglacial age.

INTERPRETATION ON EVIDENCE FROM THE UPPER GREAT LAKES

General statement.—If there were no other way than this of approaching the study of Niagara history it might never become possible to reach a decisive conclusion as to the age and origin of the gorge of the Whirlpool rapids; but the characters found in the gorge itself are not the only available facts. There are others, which have been gathered from outside but closely related areas, that are more impressive and more decisive than anything that can be seen in the gorge. It cannot be denied that the gorge may have varied its characters in some degree in consequence of the action of obscure and undiscoverable causes. Besides, to ordinary observation, even the extreme differences of width and especially of depth in the gorge are not in themselves particularly striking. The width and depth in the different sections had to be made known accurately before their import could be clearly perceivable, and this was not possible until the gorge had been surveyed and mapped and some attempt had been made to ascertain its depth by soundings or by some other method of safe inference. Not so, however, with the Great lakes. Their changes are represented by phenomena of large magnitude. Their episodes are generally clearly defined and separated, and there is little liability of mistaking the import of their characters.

The four outlets.—The cataract draws its power from Erie, Huron, Michigan, and Superior, the four great lakes above it. During the retreat of the last ice-sheet, when lake Huron was perhaps half uncovered, the waters of glacial lake Warren fell away and lake Erie was left independent of its three larger neighbors to the north, and has remained so ever since. It is the changes of these three that have most affected the history of Niagara. The relief of the boundary or rim of the watershed of the three upper lakes is such that with a slight amount of tilting this way or that, one or another of four different outlets, according to the direction of tilting, may become the way of discharge.* Only one of these, which is the present outlet at Port Huron through the Saint Clair and Detroit rivers and lake Erie, conducts the water to Niagara. One of the others, situated at Chicago and lacking only a few feet of being active at the present time, would carry the water to the Mississippi;† but this outlet has not been active since modern Niagara began its career. Another outlet that was probably active for a short time since Niagara began is at Balsam lake, in Ontario, and carried the water down the Trent valley to the basin of lake Ontario.‡ The remaining outlet, situated at North Bay, Ontario, about 70 miles northeast of the north end of Georgian bay, appears to have been active for a relatively long time.§ By this

* F. B. Taylor: "A short history of the Great Lakes," being chapter x in "Studies in Indiana geography," edited by Prof. C. R. Dryer. (Inland Publishing Co., Terre Haute, Indiana, 1897.)

† Frank Leverett: "Pleistocene features and deposits of the Chicago area." Chicago Academy of Science, Bull. no. ii, May, 1897.

F. B. Taylor: "Correlation of Erie-Huron beaches with outlets and moraines in southeastern Michigan." Bull. Geol. Soc. Am., vol. 8, 1897.

‡ J. W. Spencer: "Notes on the origin and history of the Great Lakes of North America," (Abstract) Proc. Am. Assoc. Adv. Sci. 1888, p. 199; "Deformation of the Algonquin beach, and birth of lake Huron," Am. Jour. Sci., iii, vol. xli, 1891, p. 19.

G. K. Gilbert: "The Algonquin river," (Abstract) Am. Geol., vol. xviii, Oct., 1896, p. 231.

§ G. K. Gilbert: "The history of the Niagara river." Sixth Ann. Rept. Com'rs of State Reservation at Niagara, Albany, 1890, pp. 72–73. Same in Rept. of the Smithsonian Inst., 1890.

F. B. Taylor: "The ancient strait at Nipissing," Bull. Geol. Soc. Am., vol. 5, 1894. Same in Am. Geologist, vol. xiii, March, 1894. p. 220; "A reconnaissance of the abandoned shorelines of the south coast of lake Superior," Am. Geologist, vol. xiii, June, 1894, p. 370; "The second lake Algonquin," Am. Geologist, vol. xv, Feb. and March, 1895, with "Preliminary notes on studies of the Great Lakes made in 1895," Am. Geologist, vol. xvii, April, 1896, p. 253–257; "A short history of the Great Lakes," as above.

outlet the water was conducted, after passing over lake Nipissing and the col east of it, down the Mattawa valley eastward to the Ottawa. The measured discharge of the several lakes shows that lake Erie contributes on the average only about one-ninth of the present volume of Niagara river.* It follows that if at any time since Niagara first began at Lewis-

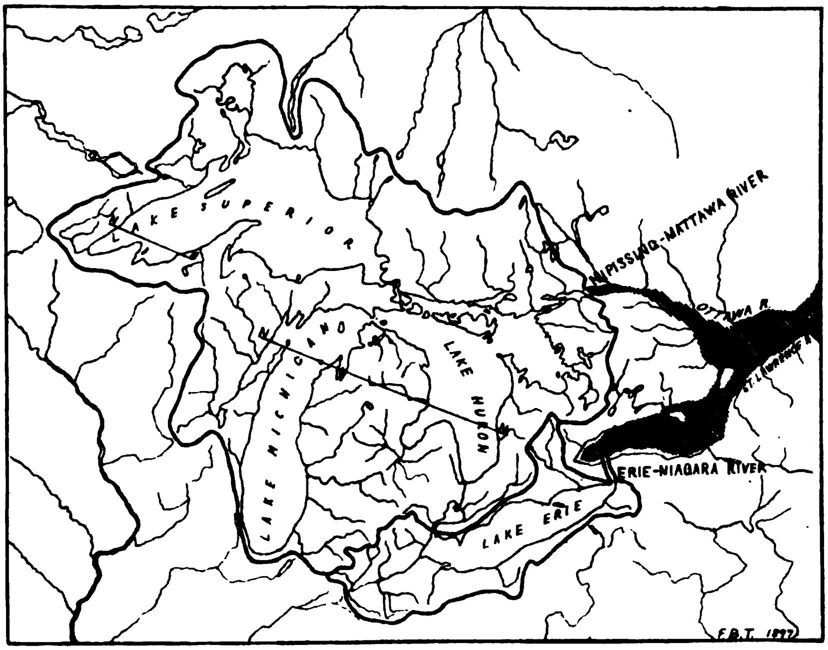

FIGURE 24.—*Hydrography of the Lake Region during the Time of Nipissing Great Lake.*

ton any circumstance led the three upper lakes to discharge by one of the other outlets, then so long as that condition lasted Niagara was deprived of eight-ninths of its water; and if this condition, being once established, lasted for any considerable time it would seem certain that

* L. Y. Schermerhorn: "Physical Characteristics of the Northern and Northwestern Lakes," Am. Jour. Sci., iii, vol. xxxiii, April, 1887.

† The heavy line surrounding the three upper lakes marks the boundary of their watershed, and the heavy line around lake Erie bears the same relation to it. The conditions shown are those of the time of Nipissing Great lake with the Nipissing-Mattawa river as its outlet. Lake Erie was then independent with the Erie-Niagara river, carrying its unaugmented overflow, as its outlet. The lake shores of that time were not exactly the same as now, but the difference was so slight that they have not been represented separately. They are now above the present lake level north of the approximate nodal lines NN, and beneath it, south of them, the level of lake Superior being 20 feet higher than lake Huron. The shaded area in the Saint Lawrence and Ottawa valleys and the basin of lake Ontario represents the approximate extent of the contemporary marine Champlain submergence.

it would leave a record in the gorge, for during that time the falls would have only the discharge of lake Erie, and the gorge made then would be shallow and narrow in comparison and it would be made much more slowly.

Nipissing Great lake.—All the lands bordering the three upper Great lakes have been explored more or less thoroughly, the old abandoned beaches have been measured and traced for thousands of miles, and the current-worn beds of the several old outlet channels have been examined. As a result, the following facts pertinent to this paper have been found: Besides a probable temporary discharge through the Trent valley, with which we are not especially concerned here, the three upper lakes discharged for a relatively long time by way of the Nipissing or North Bay outlet. The most strongly developed beach that has been found in the upper lake basins leads to the North Bay outlet and to no other, although it apparently falls but little below the present outlet at Port Huron. In its present attitude this beach is tilted so as to descend toward the south-southwest nearly 7 inches per mile, and it passes under the present lakes Huron and Michigan in their southern parts and under the west end of lake Superior. This is called the Nipissing beach, and the very large triple lake of that time is known as Nipissing Great lake.*

Nipissing-Mattawa river.—The abandoned bed of the outlet river of this great lake has been traced through the Mattawa valley from North Bay to the village of Mattawa, where the Mattawa river joins the Ottawa, a distance of about 40 miles. The descent of the river between these places was somewhat less than 150 feet, and all of it, excepting one fall or cascade of 30 or 40 feet, was accomplished by rapids of moderate declivity. In a previous paper, in which a brief account of this river was given, it was proposed to call it the Nipissing-Mattawa river.† Space permits the enumeration here of only a few of the principal facts relating to it. The region is rough and rocky, the country rock being mainly gneiss and red granite of the hardest quality. The modern Mattawa river is made up of a chain of lakes, mostly long and deep and narrow and connected by short bouldery or rocky rapids. Some of these lakes are simply canyons, standing two-thirds or three-fourths full of

* The writer proposed this name and has used it hitherto in the plural number, "The Nipissing Great lakes." The name was first suggested in a paper read by the writer before the Fortnightly Club of Fort Wayne, Indiana, Dec. 2, 1895, entitled "A sketch of the quaternary history of the Great lakes." An abstract under the same title was afterwards printed in the *Public Occurrent* (weekly), Fort Wayne, Indiana, vol. 1, no. 2, pp. 6 and 7, Dec. 14, 1895. In a recent paper on "Modification of the Great lakes by earth movement" (Nat. Geog. Magazine, vol. viii, Sept., 1897), Mr G. K. Gilbert uses the name in the singular number, "Nipissing Great lake," and speaks of it as a "triple lake." Mr Gilbert's suggestion seems to be an improvement, and the name will be used in the singular form henceforth.

† F. B. Taylor: "The Nipissing-Mattawa river, the outlet of the Nipissing Great lakes," (Abstract) Jour. of Geology, vol. v, no. 2, 1897, p. 220. Same in "Science," Jan. 15, 1897, p. 90.

water, the vertical walls of granite rising 30 to 100 feet above the water, which is in several places 250 feet deep.*

Scoured boulders.—At several places on the course of the river there are intensely bouldery deposits, which appear to be confined to certain lines or tracts and probably mark the position of one or more terminal moraines. These deposits obstruct the old rock channel at certain points, turning the river aside in new courses over obstructions and thus producing the lakes; but there are a number of stretches where for several miles there appeared to be no boulders nor any drift of the finer grades—only bare granite. Some of these places were probably the sites of rapids of moderate descent, but it is certain that this was not the case with all of them. The presence or absence of rapids in these stretches was not evident from any mark made by the rapids themselves, but was inferred from the attitude of faint old shorelines on the lake slopes near by and from the upper limit of the marks of scour in certain other rapids where these marks may be clearly seen. There are several places where boulder dams across the channel have been the site of rapids with currents strong enough to wash away all the surface material except the boulders, which were themselves moved more or less and rearranged. In two of these rapids the boulders were worn or scoured into curiously shaped forms by the play of very small pebbles and sand upon them, producing potholes in many. In some cases boulders of gneiss two feet thick were bored clear through and turned into ringstones. Boulders showing this kind of modification are plentiful at Mattawa and at Des Epines rapids, 8 miles above. In two other well marked bouldery rapids no such modification of the boulders was found. Both of these, however, lie next below lakes, one at the foot of Turtle lake and the other below a lake called Pimisi bay. The other two rapids where the scoured boulders are found lie a short distance below the debouches of streams that brought small quantities of sediment down from the highlands to the south. The mouth of Boom creek is just above Mattawa and that of the Amable du Fond river above Des Epines rapids. The inference is plain. Rapids issuing directly from lakes carried no sediment with which to wear the boulders, while those that were fed by sediment-bearing streams were supplied with the tools necessary for the work. It would seem certain that boring holes in boulders of gneiss in this way must be very slow indeed.†

* R. W. Ells and A. E. Barlow: "The physical features and geology of the route of the proposed Ottawa canal between the Saint Lawrence river and lake Huron," Trans. Royal Soc. of Can., 1895. Gives a table of altitudes and many soundings.

† F. B. Taylor: "The scoured boulders of the Mattawa valley," Am. Jour. Sci., iv, vol. iii, March, 1897.

Some idea of the size of this river may be gathered from observations made at Des Epines rapids. At that place the maximum depth was about 55 feet, with a mean of between 30 and 40 feet. The width was estimated to be between 600 and 700 feet, and yet the current at this place was strong enough to make potholes in many boulders. These dimensions resemble very closely those of the present Saint Clair river in "the rapids" at its head, a mile or more above Port Huron, where the current is nearly five miles an hour. The action of this current as it rolls along good-sized grains of sand may be seen at the upper end of the dock at Point Edward on the Canadian side.

Talon gorge.—At Talon chute, a little below the foot of Talon lake, was situated the only fall or cascade of the Nipissing-Mattawa river. Here the river fell over a ledge of "massive flesh red gneissoid granite," * at first about 40 feet high, but later apparently 10 or 12 feet lower. Below the chute is a canyon nearly half a mile long, approximately 200 to 400 feet wide, and with vertical walls 20 to 60 or 70 feet high. Except near the upper end, it has the appearance of being very deep. At the lower end the rocks are heavily glaciated, showing the usual rounded smooth forms, but in the upper part the walls give no evidence of glacial modification. The gorge widens somewhat toward its lower or eastward end. Judging by faint old shorelines on the slopes of Talon lake 2 miles above, the water passing over the brink of the falls was 15 to 20 feet deep. On the granite ledges, near the crest of the falls, there are a considerable number of potholes, mostly not deep. Some of them are 10 feet or more above the present water, and their size and wide transverse distribution indicates a large volume for the stream that made them. The boring of these potholes out of the hard granite implies in this instance a long duration of time, for the river here issued almost directly from Talon lake, the largest in the lake chain of that time, and must therefore have carried very little coarse-grained sediment. A few smaller, deeper potholes were found in the limestone also. When the great outlet river abandoned its channel the falls had become divided in two parts around a high rocky island. In the south branch of the canyon there is a thin, highly inclined bed of crystalline limestone, and this arm of the gorge is the narrower and the longer of the two. So far as could be seen, the limestone did not appear to extend more than a few rods below the falls, but its strike was apparently about in line with the gorge, and it is possible that it may have had an important influence in determining the direction of the gorge and the rate of its making. At the chute the south branch of the canyon follows this bed of limestone, while the north branch is cut out of the red granite. The modern river with its

* Ells and Barlow: As above, p. 169.

small volume has cut scarcely more than a notch in the old ledge of the falls, 4 or 5 feet deep and 8 or 10 feet wide, and it is doubtful whether all of this is the work of the modern river.

As to the age of most of this gorge there seems to be little room for uncertainty. The greater part is in all probability preglacial or interglacial, but for an estimated distance of 500 or 600 feet, or to a point a short distance below the lower end of the island around which the gorge now divides at the falls, it appears to be of postglacial age. This part is narrower, has steeper walls, and is in a general way fresher in appearance than the parts below. It is also shallower, as might be expected from the circumstances of gorge-making at this place, for on account of the large volume and the relatively slight descent the work of erosion was accomplished by a process of scour by swift flow, which is quite different from the pounding of a vertical fall. A gorge made in this way tends to be narrower and shallower than it would be if made by a vertical fall of the same stream. The writer's observations at this place were not exhaustive, but so far as they went, the exact place where postglacial gorge-making began was not made out. The influence of the bed of limestone is also an element of uncertainty. Hence it seems impossible on present information to draw a definite estimate of the time or duration of the outlet river from this gorge. Its value as a basis for a time estimate is less than that of the gorge of the Whirlpool rapids at Niagara.

Duration of the northern outlet.—It might be supposed, however, that if the Nipissing-Mattawa river flowed for a relatively long time in this valley it would have accomplished a much greater work of erosion, especially in the removal of the bouldery drift obstructions, but it is believed that such a conclusion would be a mistake. No just idea of the history of this river can be formed without taking full account of the peculiar conditions of its existence. The geological and physiographical conditions favored the minimum of erosion. With the probable exception of Talon chute, there was no place in the whole course of the river where its descent gave it sufficient power to spin boulders even of small size. Being the outlet of a great lake, the water was clear at the start. The bed and banks were mostly unyielding granite and gneiss or boulder-packed bars, and afforded very little sediment. There were no tributaries of any importance—none that brought it more than a trifling quantity of detritus—and nearly two-thirds of its course lay through lake basins, where it could neither gather nor carry sediment and where it dropped whatever small quantity it had picked up from any source above. Another element of stability under such conditions as obtained in this valley was the steadiness of volume and flow. Once begun, the river never changed appreciably, and because the bed was substantially unyielding, the direction and force of the current remained almost perfectly constant. In each of the bouldery rapids the boulders formed a closely compact floor entirely covering the finer sediments beneath them. No doubt a considerable quantity of these sediments was washed away when the river first began to flow, but as these disappeared the boulders gradually settled down closer together into positions of more effective resistance, and when the protection of the finer sediments beneath had once become complete, the unvarying volume and steadfast direction of the current left them henceforth undisturbed. Under conditions so extremely uniform it seems impossible to set any definite limit to the endurance of a boulder-packed bar in rapids of moderate velocity; and so, in spite of the apparently small work of erosion accomplished, the evidences, on the whole, indicate a long duration for the Nipissing-Mattawa river. The Nipissing beach suggests the same conclusion even more strongly.

Scheme of Correlation

With these facts before us we can hardly fail to perceive the almost obvious correlation which they suggest, namely, that Nipissing Great lake, with the Nipissing-Mattawa river as its outlet, is the equivalent in time of lake Erie, with the comparatively small Erie-Niagara river as its outlet.* On this basis the amount of erosion accomplished by the one river in this time must be the exact correlative of that accomplished by the other. Nipissing Great lake represents one complete episode in the lake history, and one in which Niagara did not have the discharge of the three upper lakes. The reduction of the morainic obstructions in the path of the Nipissing-Mattawa river to compact boulder-covered bars, the boring of potholes in the hard boulders, and the making of some part of the Talon gorge stand as the correlative of something done by the smaller river in the gorge of Niagara. In other words, from the standpoint of the lake history, we are bound to suppose a large reduction of the volume of Niagara for a relatively long time; while, on the other hand, from the standpoint of Niagara gorge history, the stronger of two alternative hypotheses leads us to the same inference. Going backward from the present in the lake history, we find that the North Bay outlet was active next before the present one at Port Huron, but the old beach at the head of that outlet is now 120 feet above the level of Georgian bay. Changes of such magnitude would seem to require a considerable duration of time, and we should expect therefore that the present episode of

*The name Erie-Niagara is suggested for the Niagara river as it was when it carried only the discharge of lake Erie. The name combines elements having both historical and geographical significance, as does also the name Nipissing-Mattawa as applied to the former great outlet river of the north.

Niagara has not been a short one. Turning to Niagara, we find that the Upper Great gorge stands out clearly and strongly as the correlative of the present episode of the upper lakes. The making of this gorge could have begun only when the outlet had been changed from North Bay to Port Huron. Hence it is plain that the lower end or starting point of the Upper Great gorge is the precise correlative of that change.

Going back one step farther in the reverse order of events, the critical episode of Niagara history comes clearly into view. In the upper lakes the next preceding episode is Nipissing Great lake, with the Nipissing-Mattawa river as its outlet. This leaves lake Erie as a perfect correlative, separate and alone, giving its relatively small and unaugmented overflow to Niagara. In the gorge of Niagara the episode next preceding the Upper Great gorge is the gorge of the Whirlpool rapids. If the relatively small Erie-Niagara river accomplished any gorge-making on its own account, its work must have been done in that section of the gorge which lies next below and contiguous with the Upper Great gorge, and the gorge which it would make would be relatively narrow and shallow. The gorge of the Whirlpool rapids has these two characteristics clearly and strongly marked, and it lies in just that position—joining onto the lower end of the Upper Great gorge—which it would have if it were made by the Erie-Niagara as the correlative of Nipissing Great lake and the Nipissing-Mattawa river.

Passing on in backward order of time to the next preceding episode of the lake history, we find that before the beginning of Nipissing Great lake the deep, narrow part of the Ottawa valley east of Mattawa was blocked by an arm of the receding ice-sheet. At that time a great glacial lake called lake Algonquin occupied the three upper lake basins and discharged its waters through the Saint Clair and Detroit rivers and lake Erie to Niagara.* Looking again for a correlative in the Niagara gorge, we find, next below the gorge of the Whirlpool rapids, the Eddy basin and the Cove section probably constituting together one continuous division interrupted only by the Whirlpool washout and the making of the two shoal ledges as explained above. The section as a whole is wide and deep and has been called, provisionally, the Middle Great gorge. This episode of the gorge history is the correlative of the latter part of the lake Algonquin episode of the upper lakes. Lake Algonquin came to an end and ceased to discharge its waters through Niagara river when the ice-dam gave way in the Ottawa valley. The same event was the beginning of lake Erie's independence and of the making of the gorge of the Whirlpool rapids; hence the contraction of width and depth at

*F. B. Taylor: "A short history of the Great lakes," as above.
J. W. Spencer: "Deformation of the Algonquin beach, and birth of lake Huron," as above.

the south side of the Eddy basin is the correlative of the breaking of the Ottawa ice-dam and the end of lake Algonquin. At the upper side of Wintergreen flat is put, provisionally, a line of division, marking an apparent place of expansion, which may be the correlative of the closing of the Trent valley outlet, supposing the discharge to have passed for a time in that direction, but the problems of the sections below the Cove are not discussed in this paper.

Relations to other Interpretations

This interpretation of the gorge of Niagara has gradually unfolded during the progress of several years' study and field work on the history of the Upper Great lakes. The work on the lakes has been supplemented from time to time by studies in the gorge of Niagara, not so thorough in detail, probably, as those made by G. K. Gilbert and J. W. Spencer, but thorough enough, nevertheless, to reveal the main characters clearly. So far as known to the writer, the first suggestion that the volume of Niagara may have varied in consequence of a discharge of the upper lakes in some other direction was made by Mr Gilbert at the meeting of the American Association for the Advancement of Science, in Buffalo, New York, in August, 1886.* Following him, the writer early adopted a modified form of the same idea, and the subsequent work on the Nipissing beach and the northern outlet has been in effect a contribution to the verification of Mr Gilbert's original hypothesis; but while he first suggested a northern way of discharge for the upper lakes, Mr Gilbert has not, unless quite recently, fully accepted the complete correlation of the gorge of the Whirlpool rapids with the activity of the North Bay outlet.†

*G. K. Gilbert: "The place of Niagara falls in geologic history." (Abstract.) Proc. Am. Assoc. Adv. Sci., 1886, p. 223. The first definite suggestion that the upper lakes discharged across Nipissing pass at North Bay appears to have been made in "The history of the Niagara river" referred to above, but apparently no attempt was made then to correlate this episode of the upper lakes with any particular section or feature in the gorge.

†In "Niagara falls and their history" (Nat. Geog. Monographs, vol. 1, no. 7, Sept., 1895) Mr Gilbert, in speaking of the data for time measurement, on page, 234, says: "At the Whirlpool the rate of gorge-making was relatively very fast, because only loose material had to be removed. Whether the old channel ended at the Whirlpool or extended for some distance southward on the line of the river is a matter of doubt." In a paper on "The profile of the bed of the Niagara in its gorge" (Abstract in Am. Geol., vol. xviii, Oct., 1896, p. 233) Mr Gilbert expresses himself in the following terms: "The shoals at Wintergreen flat and the Whirlpool rapids are correlated with epochs when the discharge of the upper lakes by the Trent and Mattawa valleys left the Niagara river and falls too small and weak for deep excavation."

This generalized statement is very satisfactory, and the present paper is in effect a partial analysis based upon the same principles. This statement appears to leave no doubt of his acceptance of the correlation of the gorge of the Whirlpool rapids with the episode of Nipissing Great lake; but in another paper read on the same day, entitled "The Whirlpool-Saint Davids channel" (Abstract, same reference), Mr Gilbert speaks reservedly, saying that it is "probable that the ancient gorge ended two or three hundred yards above the Whirlpool, but Pohlman's theory that it extended to

Dr Spencer also supposed a period of discharge for the upper lakes through a strait by way of the Mattawa valley, but he placed it earlier in Niagara history, during the recession from Lewiston to Fosters flat, and hence did not correlate it with the gorge of the Whirlpool rapids. Indeed, he postulates a concentration of full volume with a fall of 420 feet while this section of the gorge was being made. He recognized the narrowness of the gorge of the Whirlpool rapids, but he supposes it to be as deep as any other part of the gorge. ‡

The first attempt to account for the several features of the Niagara gorge in a somewhat detailed manner was that of Julius Pohlman, of Buffalo, New York, who read a paper on this subject before the American Association for the Advancement of Science at its meeting in that city in August, 1886.§ While Dr Pohlman's paper cannot be accepted today as a true analysis of the gorge history, it was nevertheless a very creditable effort, considering the fact that it was a pioneer attempt and that next to nothing was then known of the postglacial history of the upper lakes. Dr Pohlman supposed that the "preglacial Tonawanda" creek had cut a gorge from the escarpment at Saint Davids back through the Whirlpool and nearly up to the American fall, and that other small streams had cut out ravines where the modern gorge now lies, between the Whirlpool and Lewiston. He thus reduced the work of the postglacial river to a minimum, and supposed its entire duration, and hence the duration of postglacial time also, to have been only about 3,500 years. Others now following the same general idea conceive the preglacial gorge to have extended only to the upper end of the gorge of the Whirlpool rapids, and they put the duration of the river at from 5,000 or 7,000 to

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the Whirlpool rapids is not disproved." However, when the abstract of the present paper was read at Detroit, Mr Gilbert expressed himself in discussion as favoring the correlation suggestion. Messrs Wright, Spencer, and Claypole favored the view of Pohlman, or a slight modification of it.

It is interesting to compare Mr Gilbert's original hypotheses with what we now know of the lake history. In his "History of the Niagara river" he presented two maps showing hypothetical stages or episodes of the Great lakes. In plate iv Nipissing Great lake as now defined is partly anticipated, while in plate v one episode of lake Algonquin, that with the Trent Valley outlet is shown. Plate v, however, is merely a modification of Spencer's earlier hypothesis to fit glacial theory. Other more important episodes of the latter lake when it discharged southward are now recognized, but the data for unravelling their complex history had not then been collected. In plate iv the river discharging the upper three lakes is shown as passing down the Mattawa and Ottawa valleys to Montreal, and that discharging the lower two lakes follows the course of the present Saint Lawrence to the same place, showing apparently that Mr Gilbert did not correlate the marine Champlain submergence in the east with this episode of the lakes. In reality, the sea at that time entered the Ontario basin and reached far up the Ottawa valley (compare Mr Gilbert's plate iv with map no. 4 in "A short history of the Great lakes"). Mr Gilbert indicates much more land tilting than has been found to exist, and his shorelines are consequently made to dip under the present lakes toward the southwest much sooner than they do in reality. Nevertheless, his two hypothetical episodes have been verified to a remarkable degree.

‡ J. W. Spencer: "The duration of Niagara falls," as above, pp. 464–468.

§ J. Pohlman: "The Niagara gorge." Proc. Am. Assoc. Adv. Sci., 1886, pp. 221, 222; also in Trans. Am. Inst. Mining Engineers, 1888.

10,000 or 12,000 years.* There is, as pointed out above, plausibility in this hypothesis, if we base our judgment on what we can learn from the study of the gorge characters alone; but we can not, consistently with true scientific principles, ignore or fail to make the most effective use of the powerful light which the lake history throws on the Niagara problems. Those who have strong predilections for short postglacial time, however, have had much comfort from this hypothesis; so much, indeed, that they seem unconscious of the decisive bearing of the lake history.

Saint Davids Gorge

In discussing the Saint Davids gorge it seems to be very generally con-

* In his advocacy of the 7,000 to 10,000 year estimate, Mr Warren Upham rests the case for short time on grounds which appear to be erroneous and indefensible. In a recent paper by him on the "Origin and age of the Laurentian lakes and of Niagara falls" (Am. Geologist, vol. xix, Sept., 1896, p. 176) occurs the following passage: "The whole time of existence of lake Agassiz, as estimated by comparison of its shore erosion and beach accumulation with those of lake Michigan and others of the Laurentian lakes since the departure of the ice-sheet, appears to have been about 1,000 years. In comparison with this we may confidently assert that if any outflow passed for a time over lake Nipissing to the Mattawa river, it could have done so only for a few decades of years."

The attempt to estimate the duration of lake Agassiz from the shore erosion and beach accumulation of lake Michigan can hardly lead to the result claimed. The estimate of 7,500 years by Dr Edmund Andrews ("The North American lakes considered as chronometers of postglacial time," Trans. Chicago Acad. Sci., vol. ii, 1870) is often quoted; but while Dr Andrews took account of the abandoned beaches that lie above the present lake level, he made no allowance for the long time that the lake stood at levels below the present. He had no data for such allowance. The fact was not then known that the lake had stood at lower levels—50 to 100 feet lower on the shore of Illinois during all the time of lake Algonquin, and of Nipissing Great lake, and there is reason to believe that it has been slowly rising against the land since the beginning of the Champlain uplift when the discharge of the upper lakes shifted from north to south, and possibly for a considerable time before. A rising lake favors the most rapid and effective wave work on its shores. Taking Dr Andrews' own estimate and adding these other factors to it, as we must do, it will be necessary to multiply Dr Andrews' figures by at least three and possibly more.

In the article referred to (p. 175) Mr Upham quotes Bell and Barlow, of the Canadian Geological Survey, as opposed to the hypothesis of the North Bay outlet, and as "stating that they find no evidence of a great river there." These statements were made three or four years ago. Since then, in October, 1896, Dr Bell, with the writer, saw some of the evidences of the great river's action at both North Bay and Mattawa. On hearing the evidences found, Mr Barlow, while adhering to his original statement, qualified it by saying that during his work in the Mattawa valley his attention was centered mainly on other matters, and he did not take particular notice of Pleistocene features.

Mr Gilbert visited North Bay in September, 1887, and descended the Mattawa valley to the lower part of Talon lake. In "The history of the Niagara river" (the substance of an address at Toronto in August, 1889) he says: "Such data as I have at present incline me to the belief that for a time the upper lakes did discharge across the Nipissing pass" (page 72). Professor Wright and party visited North Bay, and also ascended the lower end of the valley from Mattawa over 8 miles, or to the mouth of the Amable du Fond river, in the summer of 1892; and, not knowing of Mr Gilbert's earlier visit, reported the discovery of the outlet river's bed and the confirmation of Mr Gilbert's hypothesis. ("The supposed postglacial outlet of the Great lakes through lake Nipissing and the Mattawa river," Bull. Geol. Soc. Am., vol. 4, 1892.) Between 1893 and 1896 the writer visited the Mattawa valley four times and spent altogether about three weeks studying the old river bed. Last autumn Professor W. M. Davis and Mr J. M. Boutwell spent half a day at North Bay and saw some of the marks at the head of the channel. Besides these named, no one else, so far as known, has looked for the bed of the old outlet river. Mr Upham says that if the discharge of the upper lakes ever went over the Nipissing pass "it could have done so only for a few decades of years." In view of the facts stated above, it would seem wiser for Mr Upham, who can not quote a single authority for his position, and who has never seen the two principal phenomena, neither the Nipissing beach nor the old river bed in the Mattawa valley, to suspend judgment for the present.

sidered a matter of course that that gorge was made by a small stream. To cursory observation it may seem so, but it is believed that when this old gorge is closely scrutinized where its walls are exposed on the north side of the Whirlpool, and when the effects of glaciation in widening its mouth near Saint Davids are allowed their proper value and significance, it will appear that the preponderance of evidence favors the idea that this gorge was made by a preglacial or, more likely, by an interglacial great cataract of substantially the same volume as the present falls—in short, by an interglacial Niagara—and that it suddenly stopped work at the south side of the Whirlpool basin.

Dr Spencer has forecast a cessation of the present falls 5,000 or 6,000 years hence in consequence of a change of outlet of the four upper lakes from Buffalo to Chicago, and Mr Gilbert, proceeding on an entirely different foundation of facts, has more recently forecast the same event for 3,000 years hence.* Who can say that this prospective change may not be merely a repetition of what has occurred before in the last interglacial epoch and possibly in other earlier ones also?

Time Ratios

If the whole of the Upper Great gorge was made at the measured rate (nearly 4½ feet per year from 1842 to 1890), then it took something like 2,700 years to make it. There is good reason to believe, however, that the rate was somewhat slower most of the time, so that it would probably be nearer the truth to say it has taken between 5,000 and 10,000 years. The Upper Great gorge is three times as long as the gorge of the Whirlpool rapids, so that if the latter were made at a rate one-third as fast as the former it would have taken the same time, but the volume of modern Niagara is about nine times that of the Erie-Niagara river during the Nipissing Great Lake episode. Surely, under such conditions as obtain at Niagara, the ratio of erosion in gorge-making would not be so low as 1 to 3 with the volumes 1 to 9, other conditions being substantially the same. It seems almost certain that the time consumed in making the smaller gorge was very long, probably several times longer than that required for the Upper Great gorge. The popular estimate of 7,000 to 10,000 years for the making of the whole gorge from Lewiston up surely falls far short of the truth.

For the gorge of the Whirlpool rapids no time estimate has yet been given that has much value even as an approximation. In one or two previous papers the writer has endeavored to draw aid from the example

* J. W. Spencer: "Duration of Niagara falls," as above, p. 472.
G. K. Gilbert: "Modification of the Great lakes by earth movement." Nat. Geog. Magazine, vol. viii, Sept., 1897, p. 247.

of the present American fall, but the conditions surrounding this cataract are so anomalous, permitting it to remain almost entirely stationary, that although it is apparently the best we have, it seems to be almost useless as a criterion.*

SUMMARY

For as much of the Niagara gorge as is brought under discussion in this paper, the correlations between the gorge and the lakes seem clear and complete, point for point and episode for episode. They may be summarized briefly as follows:

1. The episode of the Middle Great gorge, extending from Wintergreen flat up to the upper side of the Eddy basin, is the correlative of the latter part of the episode of lake Algonquin—that part which comes after the closing of its Trent Valley outlet, supposing the lake to have drained for a time in that direction.

2. The place of the sudden contraction of the gorge at the upper side of the Eddy basin is the correlative of the breaking of the ice-dam in the Ottawa valley and the opening of northeastward drainage—the end of lake Algonquin.

3. The episode of the gorge of the Whirlpool rapids is the correlative of the episode of Nipissing Great lake with the Nipissing-Mattawa river at its outlet—episode of the Champlain marine submergence.

4. The place of expansion at the lower end of the Upper Great gorge above the railroad bridges is the correlative of the change of outlet of the upper lakes from North Bay to Port Huron—the beginning of the Champlain uplift.

5. The episode of the Upper Great gorge is the correlative of the modern or post-Champlain episode of the upper Great lakes.

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*So long as the American fall was taken as a unit of measure, the writer's estimate of the duration of postglacial time was expressed in large figures with a very wide range between extremes. No limit short of 100,000 years or more was recognized as demonstrable, but an estimate of 60,000 to 70,000 years was considered most satisfactory. New evidence having some bearing on this problem was found in 1896 and 1897 in the drowned lower courses of the tributaries of the Saint Clair and Detroit rivers and lake Saint Clair. (F. B. Taylor: "Some features of the recent geology around Detroit," (Abstract) Proc. Am. Assoc. Adv. Sci., 1897.) The beds of all the tributaries have evidently been deepened at a time when the main river beds were abandoned, the upper lakes discharging at that time over Nipissing pass, and then have been drowned or flooded afterwards when the discharge of the upper lakes returned to this course. The drowned stream beds indicate a relatively long duration of time at lower base level, but they do not appear to support so large figures as those mentioned above. Revising our conclusions in the light of recent advances, it may be said, tentatively, that 50,000 years may be regarded as an approximate extreme limit for the making of the whole gorge of Niagara, but that it may have been as short as the estimates of Lyell (35,000 years), or Spencer (32,000 years). It ought to be distinctly recognized, however, that many of the elements of the Niagara time problem are, in the very nature of things, so uncertain in their values that no time estimate pretending to accuracy within narrow limits can be trustworthy. This is the more unfortunate because the Niagara gorge is by far the best single datum for estimating the duration of postglacial time that has yet been discovered.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 9, PP. 85-100 JANUARY 24, 1898

GEOLOGICAL PROBABILITIES AS TO PETROLEUM

ANNUAL ADDRESS BY THE PRESIDENT, EDWARD ORTON

(Read before the Society December 28, 1897)

CONTENTS

INTRODUCTION

It has seemed to me that I can turn the hour that you allow me on this occasion to the best account in the discussion of some subject connected with petroleum and its derivatives.

Petroleum has long been in the world. Man has been acquainted with it through much of his brief day. As soon as he "came to himself," in the earliest stages of civilization, we find him making use of asphalt, one of the best marked derivatives of petroleum. Asphalt took a prominent place in his arts and commerce, and frequent mention of it occurs in some of the oldest records of the race.

In later times asphalt, the representative of petroleum, lost to a considerable extent its relative importance, being replaced in several lines of service by other and more easily obtained substances, but within the last half of the present century the bituminous series, represented by petroleum and gas, has acquired an importance infinitely greater than it ever had before. It has become a factor, and by no means an insignificant one, in the commercial exchanges of the civilized world, and it has made contributions of inestimable value to the well being and particularly to the comfort of the human race.

In this modern development the new world has taken the leading part. What may be called a distinct branch of mining engineering, namely, the art of drilling deep wells, has grown out of it here. This art comes into close relations with the science of geology. It is hard to say at the present time which is the more indebted to the other, the art or the science. Each gives and each receives.

The crust of the earth contains but few mineral productions that awaken such widespread interest as the bituminous series. The search for oil and gas is attended with much of the excitement that goes with the search for the precious metals, and success is in many cases as amply rewarded in the one as in the other.

Geologists, especially if they concern themselves with the practical applications of their science, are constantly called on to answer questions with regard to petroleum, its probable presence in any given locality, its modes of origin and accumulation, the duration of its supplies. They have recognized these new demands, and discussions bearing on such questions have made large additions to the literature of the science during the last forty years. These discussions are still in progress, and important contributions to our knowledge of petroleum and its derivatives are being recorded in our own day.

In view of these facts, and despite the well worn and hackneyed nature of the theme, I feel warranted in asking you to follow me in a brief review of the *geological probabilities as to petroleum.* I use the modest word, probabilities, in this connection because it seems in all respects the proper word. Geology is a historical science, and but few demonstrations of the sort that carry mathematical certainty find place in it. We have only probabilities as to all the dates of the science; for example, as to the date of the end of the Glacial period, let alone its beginning; as to the date of the advent of man. Nay, more, we have only probabilities as to the weightier themes of geology; as, for example, the cause of glacial periods, the eruption of volcanoes, the formation of mountains, the condition of the interior of the earth. By what right, then, should we expect certainties on a subject that is one of the last to be considered in geology, and that is, by its very nature, complicated because of the fact that the geologist must depend upon the chemist for the ultimate decision of many vital points in the investigation? But I must remind you that there are probabilities and probabilities in geology. In other words, geological probabilities are of different orders. Some of them are so strongly supported that they count for certainties with many minds. In what respect they could be strengthened by subsequent discoveries it is hard to see; but we may still style our conclusions, even on such subjects, probable.

Origin of Petroleum

Among the geological probabilities as to petroleum, I mention first those which bear upon its origin. Geologists believe that *petroleum is in all instances derived from organic matter*—that is, they believe that petroleum falls into line with every other combustible body that we know on or beneath the crust of the earth. Everything that burns has borrowed its power to burn from the sun. It burns because it holds some of the sun's heat and light imprisoned in the organic substances formed by these agents. Burning is the rapid restoration of this organic matter to the simpler state from which it originally came.

To what other source can petroleum be referred? We are all familiar with the great chemical hypotheses that have been before the world for the last 30 or 40 years. The names of their authors are a sufficient guaranty of the soundness of the chemical actions and reactions invoked—that is, of the chemical possibilities concerned. To one of these theories, which has somewhat more to commend it, or, rather, somewhat less to condemn it, than the other theories of the same class, the great name of Mendelejeff, the discoverer of the periodic law, is attached. In what light the postulates of this theory are regarded by chemists I am not able to say. These postulates, in substance, involve masses of white-hot iron, buried miles below the surface in the depths of the original crust, but still reached by water percolating from the surface and charged with carbon dioxide, the whole giving rise to a somewhat complicated series of chemical reactions out of which petroleum at last emerges.

I repeat, I do not know how this theory appears to chemists, but to geologists it sounds like an echo from the eighteenth century. It goes back to Werner's day and takes its place among the "cloud-capped towers and gorgeous palaces" of the speculations of the time when cataclysmic geology was in undisturbed possession of the field.

The law of parsimony of force seems applicable to this case. It is not necessary to go so far as these chemical theories require for a source of petroleum, because there is always an organic source nearer at hand. We can roughly divide the rocks of the earth's crust into two great series; those in which organic remains are more or less abundant and those in which no traces of life are found, either because life had not been introduced at the time of their formation or because metamorphic changes have supervened since their origin, by reason of which all such traces, if ever present, have disappeared.

In the last named division neither petroleum nor any of its derivatives is ever found; all its occurrences are confined to the fossiliferous division. While the Archean rocks do not cover surface areas as large as the vast series formed in the ages of life, they are by no means insignificant in extent. Two million square miles in one continuous body, more than one-fourth of North America, are referred to this series in the Canadian protaxis alone. In the other continental masses a like distribution is recognized.

Now, if the real centers at which petroleum originates are to be found below the Archean, in the primeval crust, according to Mendelejeff's theory, the carbonated waters of the surface, essential to the process, would certainly have a shorter course in reaching these centers when descending through the uncovered Archean than by going down through thousands of feet of the stratified and fossiliferous rocks overlying them. It is hard, therefore, to see why, the whole world over, petroleum is entirely wanting in the Archean and exclusively confined to the stratified rocks. There is not an oil field in the world in rocks of Archean time. To this it may be replied that the absence of petroleum from Archean rocks may be due to the fact that porous rocks suitable for storage are not found in this series; but according to Mendelejeff the process of petroleum manufacture is in constant operation, and certainly any large stock produced within the last 5,000 or 10,000 years, not to speak of the last 50 or 100 years, would have left some clue or token upon the surface.

Further, there seems to have been a notable increase of the bituminous series as the geological ages have advanced. The maximum of their production was apparently reached in the great division that immediately precedes the present order, namely, in Tertiary time; but this increase in the petroliferous series has gone forward contemporaneously with the decrease in the internal heat of the earth. There has been, however, a gain in the total amouut of life which the rocks contain, and this roughly corresponds with the increase in the total accumulation of bituminous products above referred to.

That the organic world is an adequate source of petroleum has been abundantly demonstrated within the last few years. The demonstration was begun by Warren and Storer in the distillation of a lime soap made from menhaden oil. In this operation various compounds belonging to the bituminous series were definitely developed. This work was made known to the world about 1867–'68.

Investigation was subsequently carried still further in this line and to still more striking results by Dr Carl Engler, of Carlsruhe, Germany, who has obtained from fish oil, and afterward from lard oil, almost the entire bituminous series to which petroleum belongs. In the list of the products which he thus obtained from the sources named are to be found illuminating oil, lubricating oil, benzine, and paraffine. Engler's results were published in 1888.

The animal world has thus been definitely proved to be, at least in its higher divisions, a possible source of petroleum and its various derivatives. And now comes Dr S. P. Sadtler, of Philadelphia, who has extended a similar line of investigation to the vegetable world as well. In an important paper read before the American Philosophical Society February 5 of the present year he made known the results of the work which he had recently carried on and which he still continues in the distillation of linseed oil under pressure. He obtained by this process hydrocarbon oils analogous to natural mineral oil or petroleum, and, among other products, he produced a good specimen of scale paraffine. It is altogether probable that oils derived from other vegetable seeds would show the same characteristics. The vegetable kingdom is thus shown to be on the same plane with the animal kingdom as a possible source of the bituminous series.

Daubree, perhaps the most ingenious and successful experimental geologist of the century, advanced the same claim at a still earlier day. He declared that by the action of superheated steam upon wood he had obtained both liquid and gaseous products closely allied to petroleum. In his view the concurrent action of water, heat, and pressure on vegetable matter furnished an adequate account of the natural production. Engler's discovery is worthily supplemented and balanced by Sadtler's. From the latter we see how hasty and unwarranted the conclusion adopted by some, that the origin of petroleum always and everywhere is to be ascribed to the products of the decay of fishes.

Closely related to this latter claim are the facts pertaining to the Trenton limestone oil field of Ohio and Indiana. This is unmistakably one of the most important reservoirs of petroleum that was ever discovered; but it originated long antecedent to the appearance of fishes in the geological scale. In placing it before the introduction of fishes I do not forget the recent discovery by Mr Charles D. Walcott, director of the Geological Survey of the United States, of fish remains in the lower Trenton of Colorado. Geologists have not yet had time to assimilate this remarkable discovery and to give it its due place in the history of the life of the world; but certainly these Ordovician fishes of Colorado might as well not have been, so far as the buried life of the world at large is concerned. Not a hint of the existence of one of them has been found in the well worked formations of Ordovician time in any other part of the globe. Vast periods of time elapsed after this date, periods measured by the deposition of many thousands of feet of the various types of sedimentary rocks, before fishes appeared elsewhere in the world. The petroleum of the Trenton limestone owes nothing whatever to the vertebrate type, so far as its sources are concerned.

While geologists find such warrant as I have indicated and much besides for believing in the organic origin of petroleum, it cannot be claimed that they hold concordant views as to the manner in which the conversion of organic tissue into mineral oil has been accomplished. They recognize the process as essentially chemical in its nature and are prepared to welcome all pertinent facts and discoveries from students of this branch of knowledge.

It is easy to see how the bituminous series may result from the destructive distillation of either vegetable or animal substances enclosed in the rocks, and wherever conditions can be shown that provide for such distillation we are not obliged to go further in our search. Destructive distillation can take effect on organic matter that has attained a permanent or stable condition in the rocks, like the carbonaceous matter of black shales or coal; but it seems improbable on many and obvious grounds that this can be the normal and orderly process of petroleum production.

This production of petroleum must be in active operation in the world today; at least it seems highly improbable that a process coeval with the kingdoms of life, growing with their growth and strengthening with their strength, a process that was certainly in its highest activity throughout Tertiary time, leaving a most important record in the rocks of that age, should suddenly and completely disappear from the scene upon which it had wrought so long and upon which all other conditions appear to be substantially unchanged.

What geologists would be glad to find in nature as matching to and harmonizing with the facts with which they are obliged to reckon would be a process in which the products of the organic world are transformed into mineral oil at ordinary temperatures and with complete consumption of the substances acted upon, so that no carbon residue would be left behind. They would also expect the transformation to be accomplished while the organic matter still retained essentially its original character.

The demands of the chemists are much the same. For the origination of the petroleum of Pennsylvania, one of them, namely, Professor E. J. Mills, of Glasgow, Scotland, requires "long continued application of a gentle heat to some derived form of cellulose."

Whether such a process as the geologists are looking for is a fact of nature and susceptible of satisfactory proof or whether the demand for it is mistaken and irrational remains to be determined. Once and again support seems to have come to such a view from certain lines of reported facts. The testimony of G. P. Wall in 1860 to the effect that the production of petroleum could be seen going forward on the island of Trinidad, manifestly connected with the decomposition of vegetable tissue, has not been corroborated by later observers. Wall's testimony was in itself impressive and it was used effectively by Dr T. S. Hunt. If it had been or could be thoroughly substantiated, it would go far toward settling the question at issue.

Considerable weight has also been attached to the recent observations reported by Dr Oscar Fraas, of Stuttgart, on the occurrence of petroleum in certain coral reefs of the Red sea. Dr Fraas confidently refers the petroleum to the decomposition of the organic matter of the reef. This claim also, if fully sustained, would solve the problem as to the mode of origin of petroleum; but unfortunately the interpretation of the facts is not beyond question. Other explanations of the presence of the observed petroleum can be offered, which have at least a show of probability. If, however, further examination should confirm the claim of Fraas that petroleum is now forming in these reefs at the normal temperature of the sea and out of the organic remains of dead corals, the long controversy would be closed.

The occurrence of petroleum or its derivatives in fossil corals and shells has long been noted. The facts have been used by some as decisive proofs of the conversion into oil of the organic matter represented by the fossils; but to this it is objected that the petroleum found greatly exceeds in amount what the organic matter in question could supply. The objection seems to me well taken.

Its occurrence in peat bogs, as recorded by Binney, is not proof conclusive that it originated there.

Any theory of petroleum production to be acceptable to geologists must provide for the use of the organic substances elaborated by the lower divisions of the animal and vegetable kingdoms as well as by the higher. To limit the process to the fatty acids derived from the decomposition of vertebrates or to the oils contained in the seeds of the highest groups of plants would be ludicrously inadequate. As in the doctrines of orthodoxy, the geological test must be, *Quod semper, ubicunque, ab omnibus.* The great stocks of petroleum on which the world depends are practically independent of both these higher sources. As we have seen, some of the oil fields antedate these divisions, not by millenniums alone, but by eons.

We must not forget that the chemical actions and reactions which we set in motion laboriously and with great expenditure of force in our laboratories, in the great laboratory of nature appear to be of the simplest and easiest possible character. Witness, for example, the decomposition of carbonic acid in the cells of every growing plant.

PERMANENCY OF PETROLEUM AND ITS DERIVITIVES

It is geologically probable that *petroleum and its derivitives are permanent substances*—that is, stable in the chemical sense of the word. Petroleum, when confined in the rocks, may take the simpler form of the gas which belongs to its own series. This often happens, and in some cases, no doubt, all the oil is so transformed; but there is nothing to show that the oil or gas may not continue indefinitely within the crust of the earth when once formed there. Petroleum, for aught we know, is as durable as coal.

When petroleum is in direct contact in any way with the atmosphere a process of reduction goes on in it by which its gravity is increased through the elimination of volatile elements. When the petroleum has an asphalt base, the reduction finally results in the separation of this substance as a residue, but asphalt is in a high degree durable.

As implied in the preceding statement, we may have petroleum and gas of various geological ages. They may be recent, cenozoic, mesozoic, or paleozoic. They undoubtedly come down to us from some of the most ancient strata in the geological column that have remained unaffected by metamorphic agencies.

INABILITY OF PETROLEUM AND GAS TO DESCEND IN THE GEOLOGICAL SCALE

It is probable that *neither petroleum nor its derivatives ever descend in the geological scale.* Petroleum is specifically lighter than the liquids associated with it in the rocks. These liquids are generally saline waters, and their gravity is greater than that of fresh water, sometimes by as much as one-tenth. Oil consequently rises in the rocks by means of this well-nigh universally distributed water just as far as the possibility of movement is allowed to it. Natural gas, the most common derivative of petroleum, in like manner rises as far as it finds any open way, but no agencies are known by which either petroleum or gas can be carried to lower horizons than those in which they originate.

You will not fail to note an important consequence that follows from this principle, namely, that petroleum or gas is as old as the lowest stratum in which it is found.

In the town of Parish, Oswego county, New York, a well was drilled two years ago to a depth of 2,160 feet. It was begun in the Medina sandstone. The drill was stopped in red granite seven feet below the surface of this last-named formation. The granite was of the same character that is found in the nearest outcrops of Archean rocks—that is, on the western boundary of the Adirondack region. The series through which the drill descended was normal in every respect. There was found, successively, the Medina sandstones, red and white; the Medina shale, in characteristic showing; the Oswego sandstone and Pulaski shale of the Hudson River group; the Utica shale and a series of Ordovician limestones, 600 feet of which are referred to the Trenton. Below the Trenton, at a depth of about 100 feet and in accordance with the usual stratigraphical sequence of the district, a stratum of white Potsdam sandstone was reached. It was 47 feet thick, and a gas vein of fair strength and volume was found in it. The gas attained a rock pressure of 340 pounds when shut in.

Immediately below the Potsdam a stratum of dark Cambrian limestone was found. It contains rather obscure traces of animal life, apparently referable to Cambrian trilobites, and below the limestone, at a total depth of about 2,150 feet, the granite was reached, as above described. The discovery of gas in the Potsdam sandstone aroused considerable interest among the parties in charge, and it was deemed best to try the effect of a torpedo on the well. A light shot was lowered, designed for the horizon in which the gas was found; but by a slight miscalculation the explosion took place somewhat lower than was planned, and, as it proved, in the granite formation in part. A quart or two of granite fragments, some of them an inch in diameter, were brought up by the sandpump. The gas supply was increased somewhat by the torpedo, but nothing came from the well in the way of practical results. But there are certain facts and suggestions on the scientific side that are not without interest.

The gas struck in this well is of Cambrian age. It is thus practically coeval with *Lingulella*, *Dicellocephalus*, and their allies. It is probably the equivalent but altered form of a small stock of petroleum derived presumably from the decomposition of Cambrian trilobites and brachiopods. The Cambrian gas belongs, we may be sure, where it is found. It is in its original home. There is no source from which it could be derived in the granite foundations that underlie, and it cannot have come from above. Let alone the constant and insuperable opposition of gravitation to its descent through heavier liquids, the shale roof of the Potsdam, which proves itself able to withstand a gas pressure of at least 340 pounds to the square inch, would have had to be penetrated if any supply had come from above.

No; we have reached at last a point of beginning. There are no mysterious depths below on which we may draw in imagination for the material from which the petroleum represented by the gas here found, could be generated or for the heat that should effect the dry distillation of organic matter or for a hiding place for the carbon residue that must necessarily attend the process of destructive distillation. If the dark color of the limestone is referred to the carbon residue, then such residues are found without end in all dark colored rocks.

The stratum that here underlies the Potsdam sandstone is, as I have already said, a dark limestone, never more than 40 feet in thickness and sometimes much less. Fragments of the limestone 2 to 3 inches in length have occasionally been brought up from the wells, and in them we are able to study the character of the stratum. Like most deep limestones, it is compact and hard to drill. Because of this character, it has sometimes been named " black granite " in the well records; but there is not a trace or hint of metamorphic action about it. The contrast between the dark limestone and the red granite that underlies it is always immediately apparent to the driller. Innumerable but unidentifiable fragments of trilobite crusts make a prominent part of its substance. There seems to be very little material in it from which petroleum production could be maintained even by dry or destructive distillation.

A dozen or more other wells have been drilled to the granite in the same region. All of them agree in their records. The two principal strata below the Trenton limestone are the Potsdam sandstone and the dark limestone, already described. The drillings brought from these horizons seem normal in every respect. Certainly there is no hint of any transformation by heat. "The smell of fire has not passed on them." There is no carbon residue. The bituminous products found in them cannot therefore owe their origin to the usual form of destructive distillation.

In following the discussion to this point, I come upon a theory that is sometimes met in the speculations of our day. It is to the effect that the great stocks of our oil fields—the oil fields of Pennsylvania, for example, distributed through a half dozen distinct horizons and through thousands of feet of vertical range—have all been derived from a common and deeply buried source; and, further, that both gas and oil have been purified in the process of ascent, the highest oil in the vertical series being the highest in chemical character as well.

Inability of Petroleum and its Derivatives to rise from one Formation to another

I remark, therefore, in the fourth place, it is probable that *petroleum and its derivitives are unable to rise in the geological scale from one porous formation to another*. In other words, the principal deposits are hermetically sealed in the strata that contain them.

I have already recognized the obvious fact that in a homogeneous and permeable formation there must always be the movement that gravity would cause in separating at different levels the oil, gas, and salt water contained in it. Such differentiating movement would of course go on when oil rocks are, by the warping of the crust, bent into low arches or monoclines. Oil rocks also rise to day in natural outcrops, and more or less movement of their contents is rendered possible and necessary in this way. There are also numberless fractures and faults beside, by which the contents of porous rocks can reach the surface. The "surface indications" of gas and oil, of which we hear so much, are principally due to these last-named facts. Characteristic examples of such fractures are found in the Pennsylvania and Ohio fields; but sound observation seems to show that every deeply buried oil and gas rock is, in a normal state, hermetically sealed, and no communication in the vertical scale is possible between the porous rocks of a single section.

For the establishment of this probability I must again draw upon the experience that has been accumulated in New York within the last few years. In Oswego and Onondaga counties, of this state, natural gas has been found in large volume in wells drilled into the Trenton limestone. Near Baldwinsville, Onondaga county, the Monroe well was drilled in the late autumn of 1896. It reached the surface of the Trenton limestone at 2,250 feet. At a depth of 120 feet in this stratum a vigorous gas vein was struck, the rock pressure of which reached the amazing figure of 1,525 pounds to the square inch. I read for myself in August last a pressure of 1,370 pounds to the square inch on the gauge of this well after its gas supply had been drawn steadily upon for four months.

A rock pressure of 1,500 pounds to the square inch stands for, nay, demands, a hermetic seal. Think of it a moment! If there had been a drill to go down 150 years ago, when northern New York was still covered with the primeval forest, the same pressure would have been found here; if when Columbus discovered the New World, 400 years ago, it would have been the same; the same when the Christian era was begun, 1,900 years ago, by the birth of the babe in Bethlehem; the same when Romulus and Remus were herding their flocks on the seven hills of Rome; the same when the Pharaohs were quarrying the nummulite limestones out of which the pyramids were built. Can even the semblance of a reason be given why the pressure should have been any less when the nummulites were growing in the Tertiary seas?

All the events and epochs which I have named are "but as yesterday when it is past and as a watch in the night" compared with the ages that have gone by since the petroleum from which the gas was derived was stored in the Trenton limestone of northern New York.

Now, if the rock cover of a gas field is to any extent permeable, it would certainly seem that a pressure of over 200,000 pounds to the square foot, for this is what 1,500 pounds to the square inch means, ought to be able to find the open way. Any rock which withstands such a pressure for thousands and millions of years might as well be labeled "no thoroughfare." Similar reasoning will apply to pressures of one-half, one-fourth, or even one-tenth of the 1,500 pounds which was registered in the Monroe well.

If it had been possible for this imprisoned gas to escape at any measurable rate with a pressure of 1,500 pounds to the square inch, then the present figures must indicate a remainder of pressure after thousands and millions of years of waste. If the gas has ever escaped it should be escaping now. If it is now escaping, the pressure must be steadily falling unless the supply is being constantly replenished; but there is no source of supply except by the destructive distillation of the organic matter of the rock, and there could be but the feeblest possible supply from this source. The underlying rocks show no indications of having been subjected to the process of destructive distillation or to any unusual degree of heat. In fact, they distinctly negative such a supposition. In the case of the Monroe well, the 2,300 feet of overlying rock included several sandstones which could well enough become gas rocks if there were any source of gas at hand. In fact, these very strata are found to be important gas rocks in numerous instances in this immediate region. In the Monroe well, however, while the sandstones were normal, as respects thickness and grain, all of them were found wanting in gas to an unusual degree. In other words, while the reservoirs were present they were practically empty, and yet a great volume of gas under a tremendous pressure lay securely stored only a few hundred feet below them. Not a sign of the presence of this gas had ever escaped through the thick cover already noted, and probably no one would claim that oil would pass through strata impervious to gas. These facts, I submit, do not seem consistent with any freedom of ascent of the bituminous series from stratum to stratum. I accordingly repeat the proposition with which I set out, namely, that it is probable that neither petroleum nor the gas derived from it can rise through the impervious rocks that cover them. In other words, by impervious we mean impervious.

Structure or Arrangement of Strata the dominant Feature in Accumulation of Gas or Oil

It is probable that *in all accumulations of oil and gas the structure or arrangement of the strata involved is the dominant feature.* This conclusion is clearly a probability of the first order. A dozen years ago there were a few voices raised against certain applications of this doctrine, but at the present time I know of no opposition whatever to it. It harmonizes so well with the teachings of physics and its applications are so obvious and convincing that reasonable men cannot easily find standing place for an attack upon it.

I will not weary you with a repetition of the thrice-told tale of anticline, syncline, and monocline, but will only add that the controlling influence of structure comes out more and more clearly as the oil and gas fields of the world are adequately studied. The latest confirmation comes from Burma. Dr Fritz Noettling's excellent work on the Geological Survey of India, brought down to 1895, fully establishes the fact that the oil fields of the Irawaddy, famous for more than a century, conform in all particulars to the laws of structure that have been worked out more fully than elsewhere in the great oil fields of the United States. He shows, what we might have been ready to accept without demonstration, that anticlines and domes of Miocene sandstone exert the same influence in the accumulation of gas and oil that like features exert in the Devonian sandstones of Pennsylvania or the Ordovician limestones of Ohio.

Equality of Pressure on the contained Liquids and Gases

In the sixth place, and finally, it is geologically probable that *in the fields where salt water rises from deeply buried porous rocks under artesian pressure the same pressure will be exerted on the gas and oil which with the salt water, are the joint tenents of the rock.* In other words, the rock pressure of gas wells in certain districts is due to the salt water that follows the gas, and it can be measured by the height to which this water rises above the gas reservoir. In my judgment this probability, when duly qualified, also belongs with the few that are of the first order. The facts derived from the gas fields of Ohio and Indiana seem to me to constitute a demonstration of this claim, but as several well known geologists, especially interested in petroleum, have emphatically dissented from this view, we are not warranted in claiming more for it, to say the least, than for the conclusions which have been previously stated.

The theory referred to was from the first restricted in its application to districts in which the water found in the porous rock with the gas and oil rose under unmistakable artesian pressure and to the same height throughout the field. Shale gas was from the first distinctly recognized as demanding a different explanation of its pressure.

In regard to the salt-water fields, there is probably but one date in their history when the artesian theory can be fairly applied or tested. That date is at the very opening of the field. There are great differences in the degree of permeability in different portions of what is essentially a porous rock, and vast periods of time have been available for the pressure of the distant head to make itself felt in every pore of the water-bearing stratum. The first wells drilled in a district may be able to avail themselves of the normal pressure and to exhibit the normal rise of the salt water, but it is conceivable that after wells have been drilled in the same field by the score, the hundred, or the thousand, the original conditions may be materially interfered with, at least for the time being. The gas and oil, in the storage and adjustment of which ages have been used, may have been released and brought to the surface in weeks or even in days, and the salt water may be altogether unequal to the task of occupying the new territory open to it on such short notice. Years may be required for its movement where minutes are allowed.

So far as known, but a single important gas field has been taken in time to furnish a thoroughly reliable record. In the Trenton fields of Ohio and Indiana all the facts were noted at the beginning of their development, and the record accompanied the development, *pari passu.* From the facts thus gathered the artesian theory of gas pressure finally grew. I find it impossible to believe that the remarkable coincidences between observation and theory in these cases can be fortuitous. That the theory does not find support in the later experience of the Pennsylvania fields is no ground for surprise. Two explanations of this want of agreement are possible, as we shall presently see. The theory would not find support in the later stages of the very field from which the initial facts for its foundation were gathered. The salt water still rises in some wells to the same height as formerly, namely, 600 feet above tide, but the rock pressure of the gas ranges from a quarter or an eighth of the original figure to zero; but every step of the decline has been observed and noted. The figures that entered into the original theory were facts at the time they were used, and a rational explanation can be given of the conditions that have since supervened and are now existing. That another element can enter into this rock pressure I have always recognized. This element is the expansive power of the gas itself. It is seen especially in shale gas fields, where no water, fresh or salt, is associated with the gas. In such cases the artesian theory, of course, is not applicable.

The highest pressure that I have noted in shale gas wells previous to the last summer was less than 200 pounds to the square inch. During the present year I have had an opportunity to study the gas production of central New York, and to my surprise I found that the gas derived from the Trenton limestone in that region exhibits the unmistakable characteristics of shale gas. One anomalous and thus far inexplicable fact, however, comes into view in connection with it, namely, its amazing rock pressure. I have already stated the initial rock pressure of a single well as 1,525 pounds to the square inch, a higher figure than ever recorded before in gas wells of any description, so far as my knowledge goes.

This rock pressure bears a certain relation, thus far undetermined and unexplained, to the depth at which the gas is found. I do not propose to consider this subject now, but it is evident that the extraordinary figures found in this field require us to add an important qualification to the artesian theory of rock pressure.

Trenton limestone gas, whether found in reservoir rocks associated with salt water or in thin bedded limestones or shales which carry no water, has the same chemical and physical properties, and the compression under which it is found must have the same root in both cases. That root, as the later facts show, is not the weight of a salt-water column, as I once believed, but the expansive power of the gas itself, modified in some unexplained way by the thickness of the overlying section. In cases where the artesian theory of rock pressure is applicable, the compression due to the expansive power of the gas is less than that which the weight of the salt water gives, and is therefore marked and measured by the latter elements. This is the qualification which the new facts oblige us to add to the artesian theory.

Duration of Petroleum Supply

I have now completed the task which I set for myself. I have pointed out some of the principal geological probabilities as to petroleum and its derivatives. I hope that you will not find reason to complain of an undue amount of subjective color in my statements.

I am well aware that there are within the limits of our ever widening science many larger and more important subjects than that which I have brought before you, but this, too, deserves its "day in court." In fact it has some peculiar claims on geologists. Petroleum is a form of stored power, and geologists know better than other men the priceless value of such accumulations. They know that on them the well being and progress of the race largely depend, and that without them civilization cannot long maintain the pace which the nineteenth century has set. They know that these stocks of buried light and heat and power are small at the best and demand the most careful husbandry. They know, too, that petroleum and its derivatives, by virtue of their essential characteristics, are especially exposed to the wastes that come through ignorance, recklessness, or speculative greed, or through all combined. It is this liability that constitutes the peculiar claim of which I made mention a moment ago. It will be a reproach to our science to have the experiences of Oil Creek, Pittsburg, Findlay, and Baku indefinitely repeated. It will be a lasting reproach to have the important exploitation of petroleum restricted, by the exhaustion of its stocks, to the century in which it was begun and 50 years of which still remain.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 9, PP. 101-110 JANUARY 25, 1898

NIAGARA GORGE AND SAINT DAVIDS CHANNEL

BY WARREN UPHAM

(*Read before the Society December 30, 1897*)

CONTENTS

INTRODUCTION

Having recently again examined the Niagara falls and gorge with especial reference to the older channel of Saint Davids, I believe that a most important element in the history of the gorge erosion has been overlooked by some observers, and that by others its evidences have been misunderstood. This paper shows that the small preglacial stream which eroded the Saint Davids and Whirlpool channel, having a great depth beneath the river in the Whirlpool, must have flowed for a considerable distance, before reaching that depth, in a gradually widening and deepening ravine, coinciding with the present gorge along the Whirlpool rapids. Because the Niagara river found there a drift-filled narrow ravine, which it cut to the present size of the gorge, its erosion took place in that part by rapids and cascades. Southward from the head of the old ravine the river has eroded its gorge by a great vertical cataract, under which the masses of the Niagara limestone, rolled about by the power of the waterfall, have worn the river bed to a maximum depth of nearly 200 feet beneath the water surface.

The narrowness of the gorge along the Whirlpool rapids is therefore attributed to the conditions of the river erosion here indicated, rather than to decrease of the volume of the river (which several geologists have thought probable or certain) by diversion of the water of the upper lakes to flow from lake Huron eastward. Studies of the glacial lake Agassiz and of the Laurentian glacial lakes convince me that the progress of the epeirogenic uplift of the northern United States and Canada from the Champlain depression was too rapid to accord with the hypothesis of any outflow from lake Huron toward the east during the long time that would be required for the Niagara river, while thus diminished, to erode the gorge along the Whirlpool rapids.

The explanations here given to account for the variation in the width of the Niagara gorge, and for its partly very rapid and partly very deep and gently flowing river, with the relation of this gorge to the Saint Davids channel and the upper continuation of that channel by a ravine, accord mainly with Dr Julius Pohlman's discussion of the Niagara history; but his conclusion that the age of the river and of Postglacial time has been only about 3,000 years is here regarded as probably less acceptable than a higher estimate. The present writer thinks that the Niagara gorge implies for the Postglacial period, in harmony with Professor N. H. Winchell's discussion of the recession of the falls of Saint Anthony, a duration between 5,000 and 10,000 years.

Niagara Gorge

PHYSICAL FEATURES IN GENERAL

A gorge about 6½ miles long, extending southward from the Niagara limestone escarpment at Lewiston and Queenstown to the apex of the Horseshoe falls, has been eroded by the river since the withdrawal of the border of the continental ice-sheet from this district. The width of the gorge at its top varies mainly from 1,000 to 1,500 feet, but is only 650 to 800 feet for three-fourths of a mile along the upper part of the Whirlpool rapids and at the railway bridges. The depth from the brink of the gorge to the river is mainly about 300 feet, but is decreased above the rapids to about 225 feet. To this depth, however, must be added that of the river itself, making the whole depth of the gorge to the bottom of the water somewhat more than 400 feet at its northern end, at the Whirlpool, and between the railway bridges and the falls.

The sides of the gorge through all their length, excepting at the Foster flats and on the north side of the Whirlpool, are nearly or quite vertical in the upper part, which consists of the Niagara limestone, and are very steep below, where a talus is formed by the fallen debris of the limestone and of the underlying shales and the inclosed beds of limestone and sandstone. These strata are nearly horizontal, but have a slight dip southward, which, according to Spencer, amounts to about 75 feet in the whole extent of the gorge, being least (only 10 feet) in the distance of three miles between the Whirlpool and the falls.

No appreciable difference in the amount of subaerial decay and change, or weathering, of the rock walls is found when we compare the older northern part of the gorge and the newer southern part. In a very long geologic period the precipitous walls would be reduced to gentle slopes and would become indented by wide tributary ravines; but scarcely any perceptible progress toward this result has been made during the geologically very short period since the gorge began to be eroded.

FROM LEWISTON TO THE WHIRLPOOL

In this older part of the gorge, measuring 3½ miles, the river descends about 31 feet, from 280 to 249 feet above the sea; and in its further course of 7 miles, to lake Ontario, it descends, at the ordinary stage of water, about 2 feet. After its narrow egress from the Whirlpool the river flows some 50 rods with its surface ruffled by the force of its current; next it is smooth for about half a mile; thence, adjoining the broken and irregular northwestern side of the gorge (called Foster flats), the stream is narrowed (having a minimum width of about 300 feet) and runs a mile in foam-crested rapids; through the next mile it has a very strong current, but little or no foam and broken water; and along the remaining distance of about a mile to the Niagara escarpment and Lewiston the current is less and can be stemmed by the river steamers.

Owing to the formerly much lower level of the western part of lake Ontario and its gradual rise to its present height, to be explained in later pages in treating of the Laurentian glacial lakes and the Champlain and Recent epeirogenic uplift of the region, the river eroded a channel at Lewiston and northward far below its present surface, its depth of water at the mouth of the gorge being 96 feet. Its depth in the heaviest part of the rapids adjoining the Foster flats is computed by Gilbert, from the velocity and volume, to be about 35 feet, and he estimates the depth to be about 100 feet for half a mile next above these rapids to the other very short rapids at the shallower and narrowed egress from the Whirlpool.

The selection of this route by the Niagara river when it was first brought into existence by the melting away of the ice-sheet here and the reduction of the glacial lake Warren to its successors, lakes Algonquin and

Iroquois, and the probable conditions of the erosion of this part of the gorge, will be considered further on in their relation to the Saint Davids channel.

THE WHIRLPOOL

In the huge caldron of the Whirlpool the waters of the river, coming in from the southeast, sweep around continually to the left, bearing many logs and other floating objects, while a part of the surface water on the right of the entering rapids, with a deep undertow, pours forth to the northeast, making a right angle with the course of entrance. The minimum and maximum diameters of the pool are about 1,100 and 1,800 feet, and its depth is estimated by Gilbert to be about 150 feet.

THE WHIRLPOOL RAPIDS

Along a distance of one mile, from the railway bridges to the Whirlpool, the river rushes madly in most majestic rapids, having a descent of 70 feet, from 350 to 280 feet above the sea. Its width is reduced for three-fourths of a mile to about 400 feet, and its depth, according to Gilbert's computations, is about 35 feet.

FROM THE RAPIDS TO THE FALLS

In the two miles next to the falls the river, varying there from 500 feet to nearly 1,000 feet in width, has a smooth and gentle current, which becomes strong only in approaching the head of the rapids, the total descent in these 2 miles being about 3 feet. The foot of the falls is thus 353 feet above the sea, and the crest of the American falls is about 517 feet, and of the Horseshoe or Canadian falls 510 to 512 feet above the sea. In half a mile and four-fifths of a mile, respectively, above the American and Horseshoe falls the river descends in mostly shallow rapids about 55 feet, the smooth current at the head of Goat island having its surface 570 feet above the sea or 3 feet below the mean level of lake Erie.

Soundings of the river between the falls and the Whirlpool rapids, made in 1875, by the United States Survey of the Northern and Northwestern Lakes, as shown on the detailed map published by this survey (to which I am indebted for the foregoing measurements of the widths of the river and gorge), range from 107 to 189 feet in mid-channel. The maximum depth is opposite Prospect park, and thence a depth of 150 to 160 feet extends two-thirds of a mile northward.

SAINT DAVIDS CHANNEL

FROM SAINT DAVIDS TO THE WHIRLPOOL

At the little village of Saint Davids, about 2½ miles west of Lewiston and Queenstown, the Niagara escarpment is broadly indented for a width of about one mile by a preglacial stream valley, which extends southeastward, in the direction of the Whirlpool, about 1½ miles. At its head, this old valley or channel, as it now has expression in the surface contour, is filled up evenly to the adjoining country with drift deposits, partly consisting of kame and esker gravel and sand and partly of underlying till.

The continuation of the preglacial channel, however, although at this present water divide filled and concealed by the glacial drift, is revealed 1 to 1½ miles farther southeast by the ravine of Bowman creek, and especially by the deep basin of the Whirlpool, where only drift forms its northwest side, in remarkable contrast with the inclosing rock walls of all the Niagara gorge excepting at that place. Professor C. H. Hitchcock informs me that nearly all the drift there filling the old channel is boulder clay or till, most stony in the lower part of the section, and perhaps divisible in two or three deposits, laid down during successive stages of the Glacial period.

PROBABLE PREGLACIAL EXTENT ABOVE THE WHIRLPOOL

In the careful studies of the history of the Niagara river and gorge by Pohlman * and Gilbert,† as in the earlier observations of Lyell and Hall, the coincidence of the postglacial Niagara gorge with the preglacial Saint Davids channel at the Whirlpool is clearly recognized. The present river here has washed out the drift that filled the ancient channel and apparently reached to the bottom of the Whirlpool, about 130 feet above the sea. Thence the preglacial Saint Davids stream bed, beneath the drift, has probably this depth of 117 feet below the level of lake Ontario, or more, along its course past Saint Davids and onward to the deep central part of the Lake Ontario basin. The preglacial stream, as Pohlman has shown, drained the shallow Tonawanda valley, but not the area of lake Erie, which was tributary by a preglacial outlet, discovered by Spencer, along the present Grand River and Dundas valleys, to the west end of the area of lake Ontario, while that area was a river basin with free drainage.

At the Whirlpool the Saint Davids stream, according to Pohlman, plunged down in a cataract from the hard Medina sandstone bed, which is underlain and overlain by soft shales. Having at this place eroded a valley or ravine 400 feet deep below the Medina falls and a quarter of a mile wide, this preglacial stream doubtless also had cut an important

* Proc. Am. Assoc. Adv. Sci., vol. xxxii, 1883, p. 202; vol. xxxv, 1886, pp. 221, 222. Trans. Am. Inst. Mining Engineers, vol. xvii, Oct., 1888, pp. 322–338, with maps and sections.

† Sixth Annual Report of the Commissioners of the State Reservation at Niagara, for the year 1889, pp. 61–84, with 8 plates (maps and sections); also in the Smithsonian Report for 1890. Monographs of the National Geographic Society, vol. 1, Sept., 1895, pp. 203–236, with 21 figures in the text.

ravine, though of smaller size, along its higher course for a considerable distance before reaching the site of the Whirlpool. Dr Pohlman supposes, and I think with sufficient reason, that the Saint Davids ravine reached along the part of the Niagara gorge occupied by the Whirlpool rapids, having a middle vertical fall over the Clinton limestone and terminating at an upper vertical fall over the Niagara limestone, beyond which, in its approach from the south, the stream was only a little lower than the adjoining country.

EFFECT ON THE RECESSION OF THE FALLS

Immediately after the departure of the ice-sheet and the withdrawal of the ice-dammed lake Warren, the Niagara river began to erode its gorge, and it has continued in this work, under varying conditions, to the present time. It found a lower passage along the course of the gorge to Lewiston than in the course of the preglacial channel, deeply drift-covered, between the Whirlpool and Saint Davids. Perhaps the erosion of the gorge below the Whirlpool had been in some part accomplished by small preglacial streams, one cutting into the escarpment at the north and another tributary to the Saint Davids channel at the Whirlpool; but these streams, if any such existed, were much smaller and of less geologic age than that flowing past Saint Davids. There appears to have been no massive cataract like the present Horseshoe falls, but rather a series of rapids and low cataracts or cascades, along the greater part of the distance from Lewiston to the Whirlpool during the erosion of that part of the gorge, as is indicated by the shallowness and rapids of the present river.

The action of a high waterfall, with great volume of water, precipitated over a hard rock stratum of which large blocks give way and fall because they are gradually undermined, as in the Horseshoe falls, is well compared by McGee to the deep wearing of potholes. The fallen blocks are moved under the powerful impact of the high cataract and wear a deep channel, attaining near the foot of the present falls the depth of almost 200 feet under the river level. Such cataract action of deep channel wearing may be supposed to have produced the great depth of the Niagara river at the mouth of the gorge; but I think that this is better attributed to the usual process of stream cutting at the time of depressed level of this part of lake Ontario, which is otherwise known by its lower inclined beaches extending here under the lake. Deep cataract channeling is more surely indicated between the Foster flats and the Whirlpool for a distance of about a half mile, implying that any tributary of the Saint Davids channel which may have aided toward the erosion of the gorge could not have cut down to the present river surface.

Above the Whirlpool it seems very clear to my mind that the gorge erosion was much aided by the preglacial Saint Davids stream for the distance of one mile occupied by the great rapids. Here the major part of the depth and width of the gorge had probably been already eroded before the Ice age, being then filled with drift, which the postglacial river easily removed as soon as its gorge toward Lewiston was sufficiently deepened. No powerful falls have there cut a deep channel, and the river consequently has a constricted and very rapid course. Above the old Saint Davids ravine, however, a massive waterfall has operated along the latest distance of nearly two miles of the gorge, giving to the river there its great depth.

Effect of the Laurentian glacial Lakes on the Niagara Gorge Erosion

GLACIAL LAKES ABOVE NIAGARA RIVER

Among the conditions which have been supposed to cause the Niagara river to vary from its present size, only one would produce a great and long-continued diminution of the river, so giving for a large part of its history only very slow erosion of the gorge. This hypothetical factor in our problem, which has been assumed by Gilbert, Wright, Spencer, and Taylor to considerably prolong the time of the gorge erosion, is the diversion of the outflow from the basins of the three lakes above lake Erie, then confluent and forming the glacial lake Algonquin, to forsake its present course and pass eastward from Georgian bay, at first by the way of lake Simcoe and the Trent river to lake Ontario, and later by lake Nipissing and the Mattawa river to the Ottawa.

But differential elevation of the land from its Late Glacial or Champlain depression took place here, as on the area of lake Agassiz, as soon as the land was unburdened by the glacial retreat. This northward uplift was in progress while yet the ice-barrier remained farther north and northeast, holding in succession the glacial lakes Warren and Algonquin, besides several earlier and smaller glacial lakes which became merged in lake Warren, on the upper part of the Saint Lawrence River basin. In the areas of lake Agassiz and of the Laurentian lakes alike, the uplift was nearly completed during the existence of the glacial lakes, as is known by the almost undisturbed horizontality of the latest and lowest glacial lake beaches. Finally lake Algonquin, by the northeastward land elevation, became divided into its successors, lakes Huron, Michigan, and Superior.

Instead of the hypothesis of a long continued eastward outflow from lake Algonquin, my studies convince me that the Trent and Mattawa outlets were occupied successively during only a brief time, or, more probably, that these outlets were obstructed by the receding ice-front until after the land there had risen from its Champlain depression to such altitude that the Saint Clair and Detroit rivers continued to be constantly the outlet from the upper lake basins, sending their waters to the Niagara river and falls during all their history.

GLACIAL LAKES BELOW NIAGARA RIVER

Lakes Algonquin and Iroquois were contemporaneous, and the Ontario basin inclosing lake Iroquois was at the same time uplifted toward the northeast, with inclination of its earlier shorelines, and with gradual rise of the lake on the land westward because its outlet at Rome was raised much more than the western part of the basin. While these two glacial lakes were undergoing such changes, a lobe of the mainly retreating but wavering ice-sheet lingered on the highlands north of lake Ontario; and twice its moderate readvance was recorded by deposits of till intercalated with the stratified beds of a lacustrine delta in the extensive section of Scarboro heights near Toronto. The uplift of the Iroquois basin, as well as that of the Algonquin basin, is thus shown to have been far advanced and nearly completed during the continuance of their ice barriers.

Latest, the glacial lake Saint Lawrence, held by the final blockade of the waning ice-sheet on the Saint Lawrence valley below Montreal, extended into the lake Ontario basin with a depth of about 150 feet above the Thousand islands, but with its water level beneath the present surface of the west part of this lake. In like manner with the earlier lake Iroquois the progressing northeastward uplift caused the level of the lake Saint Lawrence and afterward of lake Ontario to rise upon the land in the southwest part of the Ontario basin. It was during these late stages of the lacustrine history of this region that the deep channel of the Niagara river at the mouth of its gorge may have been eroded, the channel being subsequently partially refilled with water by the continuance of the northeastward land elevation.

Epeirogenic Uplifting contemporaneous with the glacial Lakes

It has been already quite fully noted in the foregoing references to lake Agassiz and the glacial lakes of the Saint Lawrence basin that the area which had been ice-covered and depressed under the weight of the thick continental ice-sheet was gradually uplifted, and to a greater height at the north than at the south, during the removal of the ice burden. While lakes Agassiz and Warren still existed the northern parts of their areas were raised, in comparison with their southern outlets, 300 to 400 feet or more. It is also found by the present inclinations and relationship of the successively formed shorelines of these and the other associated glacial lakes that this epeirogenic movement proceeded as a permanent wave of land elevation from the periphery of the old ice-sheet inward to its central area.*

Epeirogenic Movement continued to the present Time

The basin of Hudson bay, in the central part of the glaciated area of North America, is ascertained by Dr Robert Bell's observations to be now slowly rising, mainly at the rate of a few feet in a century; but perhaps this uplift has ceased, as Mr J. B. Tyrrell thinks, in the vicinity of the mouths of the Nelson and Hayes rivers, on the southwest coast of the bay. On our Atlantic coast, from Boston to Cape Breton island, where the reëlevation from the Champlain depression ranged upward to a maximum of about 300 feet in Maine, an ensuing subsidence of the land—that is, an epeirogenic movement of opposite direction—has lately taken place and is probably still very slowly in progress, its maximum amount near the head of the bay of Fundy being apparently at least 80 feet. In southern Sweden the Champlain depression was succeeded during the retreat of the ice-sheet by reëlevation of the land somewhat above its present height; next it was again depressed, but less than before; and from this second depression it is now slowly rising at a maximum rate of 2 or 3 feet in a hundred years.

These notes of the continuance of the great Quaternary epeirogenic movements of the continental areas which suffered glaciation are presented for the purpose of directing attention to their inconstancy, oscillations, and reversals. From the consideration of these well ascertained epeirogenic changes, it seems to me that the evidence of very slight tilting of the Laurentian Lakes region now taking place, as made known by surveys of precise leveling which give comparisons between dates less than forty years apart, should not† be regarded as an important basis for predictions of changes of the course of drainage from these Laurentian lakes, turning their outflow away from the Niagara river to the old glacial Chicago outlet 2,000 to 3,000 years hence.

Duration of Niagara Falls and the Postglacial Period

In our consideration of the time occupied by the Niagara river in the erosion of its gorge we find, as I think, ample reasons for distrusting the

* Bull. Geol. Soc. Am., vol. ii, March, 1891, pp. 243–276; Journal of Geology, vol. ii, May–June, 1894, pp. 383–395; Am. Jour. Sci., iii, vol. xlix, Jan., 1895, pp. 1–18, with map; Am. Geologist, vol. xviii, Sept., 1896, pp. 169–178; The Glacial Lake Agassiz, Monograph xxv, U. S. Geol. Survey, 1896.

† G. K. Gilbert: "Modification of the Great lakes by earth movement." National Geographic Magazine, vol. viii, Sept., 1897, pp. 233–247, with seven figures in the text.

arguments and computations of Spencer,* which give 32,000 years as the age of the Niagara river. About three-fourths of that period are derived from the hypothesis of the eastward outlet from the upper lakes, which, as I believe, is untenable, or, at the most, had only a very short existence. Leaving out that element of the problem as insignificant and dividing the length of the Niagara gorge (about 6½ miles) by the recent rate of average annual recession of the falls (nearly 5 feet), we have approximately 7,000 years, as announced by Gilbert at the Buffalo meeting of the American Association for the Advancement of Science in 1886, as the probable time required for the erosion of the gorge.

This measure, which (not to be too exact in figures depending on the varying conditions of the Niagara history) we may place in round numbers as between 5,000 and 10,000 years, is of great interest to geologists because it is at the same time the duration of the period since the end of the Ice age, or, speaking more definitely, since the retreat of the continental glacier from the northern United States and Canada. It may be so accepted with confidence, for it agrees with the estimates and computations independently made for the same period by Professor N. H. Winchell, from the recession of the falls of Saint Anthony; by Dr Andrews, and recently also by Mr. Frank Leverett, from the shore erosion of lake Michigan and the accumulation of sand at its south end; by Professor G. Frederick Wright, from the filling of depressions among kames and eskers, and from erosion by streams tributary to lake Erie; and by Professor B. K. Emerson, from postglacial deposition in the valley of the Connecticut river. In Europe, likewise, numerous estimates of the lapse of time since the Glacial period, as collated by Hansen, are found to be comprised between the limits of 5,000 and 12,000 years, being thus well harmonious with the measure given us by Niagara falls.

*Am. Jour. Sci., III, vol. xlviii, Nov., 1894, pp. 455–472. Am. Geologist, vol. xiv, Nov., 1894, pp. 289–301. Eleventh Annual Report of the Commissioners of the State Reservation at Niagara, for the year 1894, pp. 99–117, with maps, sections, and views from photographs.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 9, PP. 111-162, PLS. 6-10 FEBRUARY 8, 1898

DRIFT PHENOMENA OF PUGET SOUND

BY BAILEY WILLIS

(*Presented before the Society December 29, 1897*)

CONTENTS

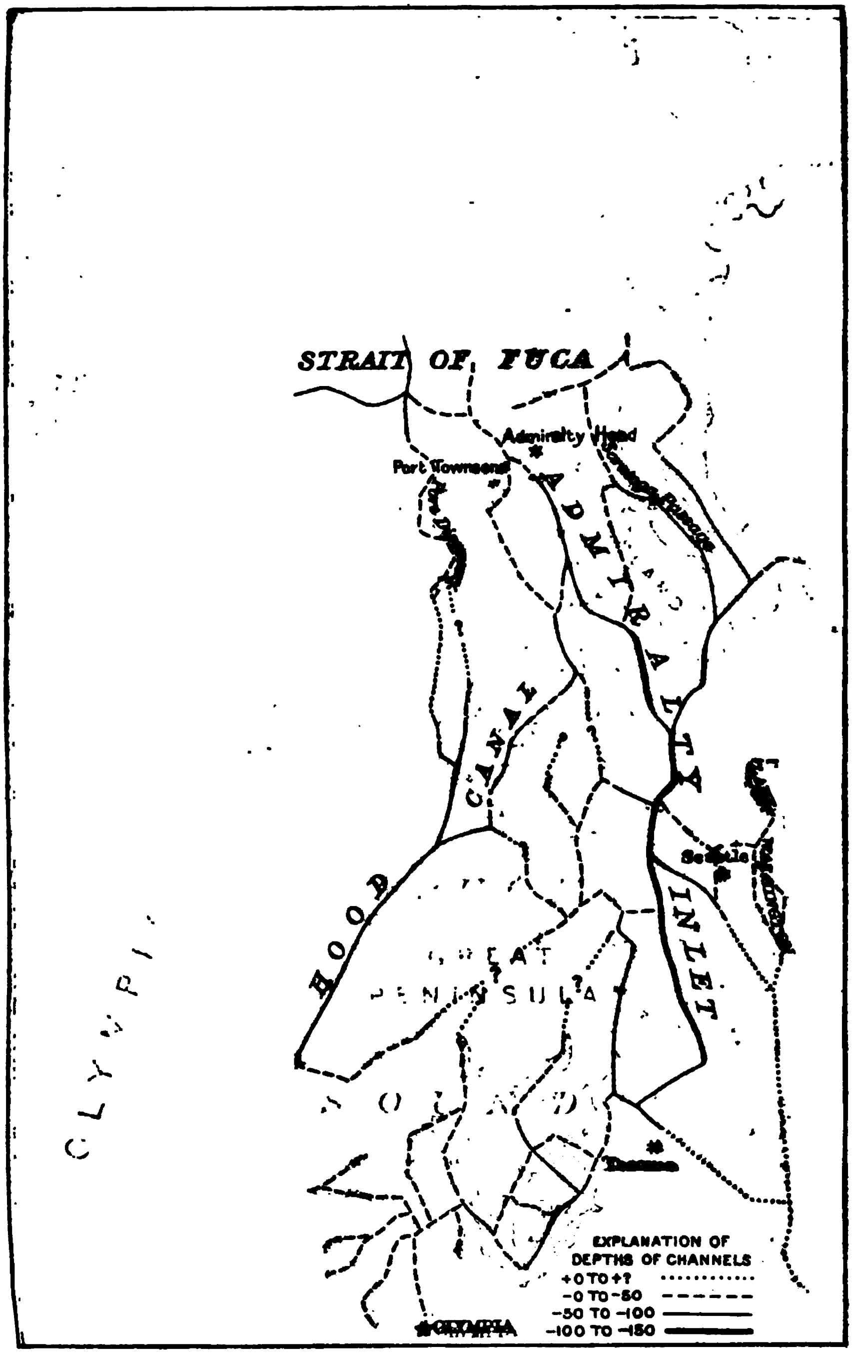
Introduction

In the following paper I propose to present some facts of topography and of Pleistocene geology bearing upon the origin of the peculiar physiography of the Puget Sound basin. The observations were made during the summer of 1896 in the southeastern portion of the Sound basin, in the course of a careful survey of the Tacoma quadrangle and the adjacent districts. I was assisted by Mr George Otis Smith, of the United States Geological Survey, and was so fortunate as to be associated during the inception of the work with Professor I. C. Russell, who had spent the three weeks preceding in a reconnoissance of the shores of Admiralty inlet. The observations would have been far less complete and their interpretation less definite but for the aid and helpful discussion given me by these geologists.

General Relations

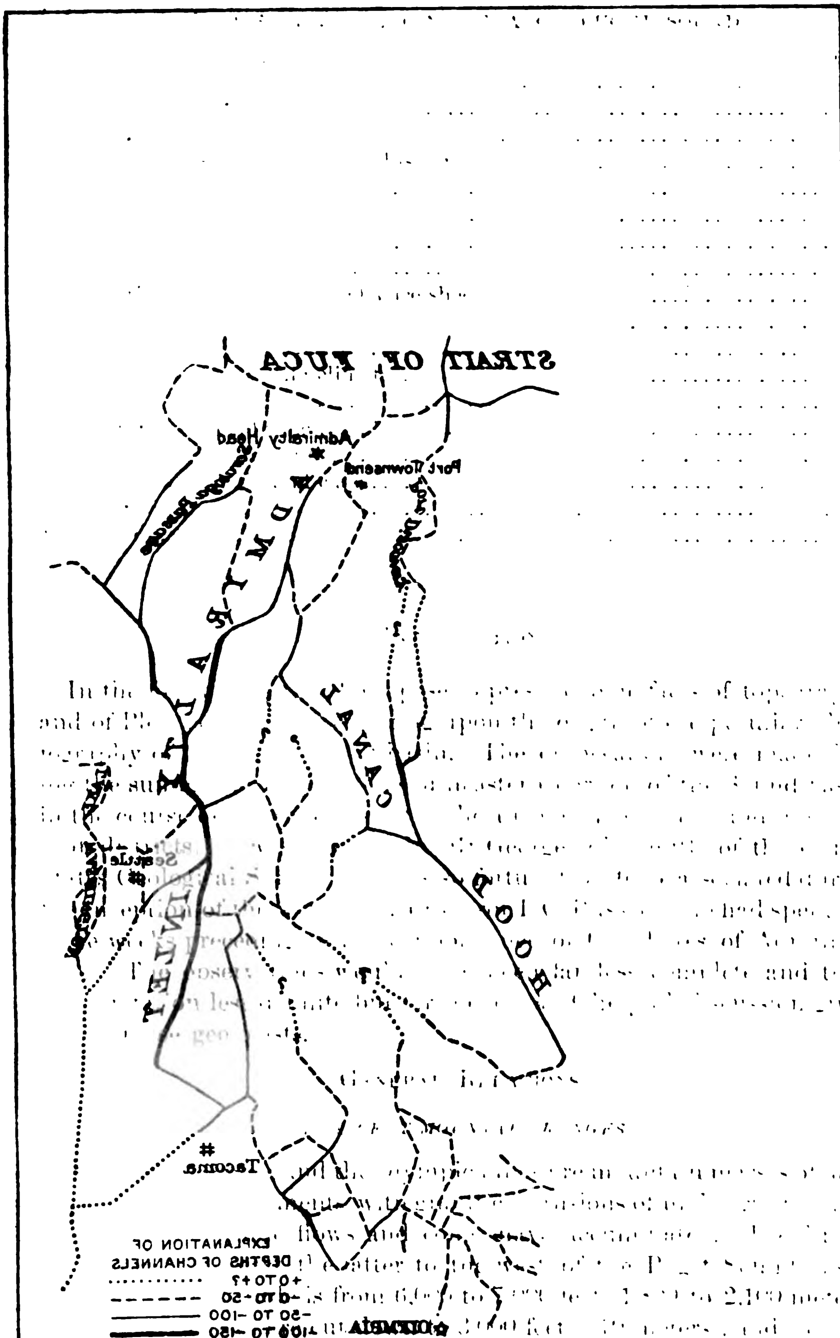
ADJACENT MOUNTAIN RANGES

The Cascade range and the Olympic range are mountain masses of Miocene and earlier sediments, with granitic intrusions of undetermined age, upon which volcanic flows and cones have accumulated. The former range lies to the east, the latter to the west, of the Puget Sound basin. Their general altitude is from 6,000 to 7,000 feet (1,800 to 2,100 meters) above sea. Passes are cut down to 3,000 feet (910 meters), and isolated volcanoes rise far above the more numerous peaks of plutonic and sed-



PUGET SOUND BASIN

Showing network of hollows and their depths with reference to sealevel



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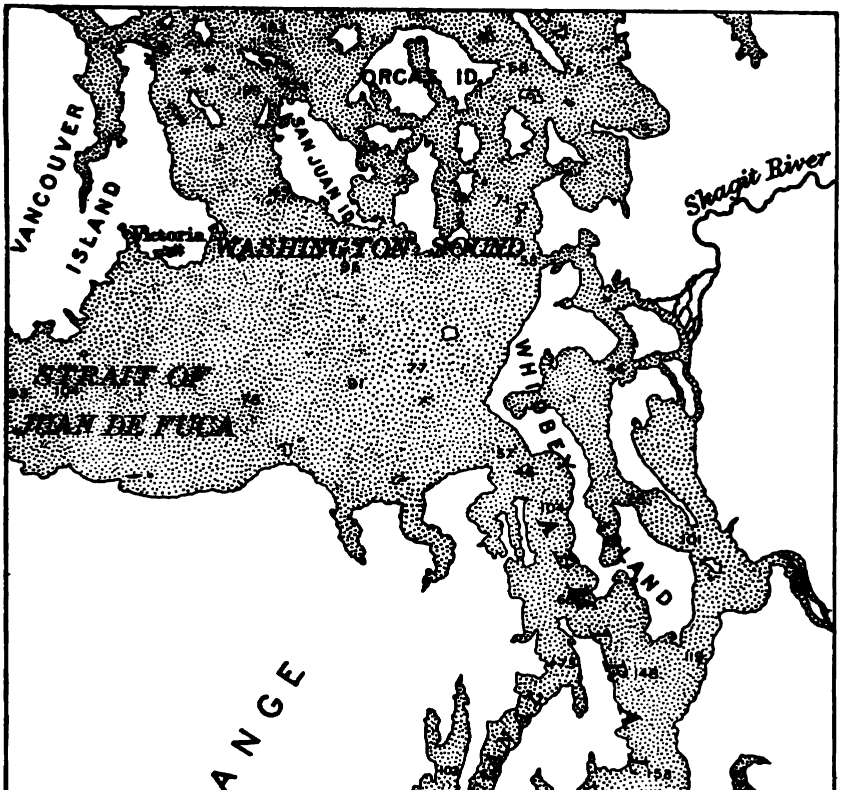


WATER AREAS STIPPLED. DEPTHS IN FATHOMS.

16 0 16 32 MILES

PUGET SOUND BASIN

Showing the extent of the present submergence to sealevel

imentary rocks. Mount Rainier, the largest and highest, holds its crater rim at 14,519 feet (4,426.5 meters) above tide. The ranges are profoundly dissected, with development of amphitheaters and acute culminating peaks such as are called by the French " dents " or " teeth." The scenic type is that peculiar to a region which has long harbored valley glaciers below the culminating summits, as the Alps now do. The space between the foothills of these ranges is about 60 miles (100 kilometers), and from summit to summit about 100 miles (160 kilometers).

THE EOCENE GEOSYNCLINE

A wide geosyncline lies between them, extending from north to south, with southern pitch. South of the Olympics the trough widens westward to the Pacific ocean, but its main axis is prolonged to the Columbia river and continued in the Willamette valley in Oregon. In Eocene time this geosyncline was a basin in which fresh and brackish water sediments accumulated to a depth of 9,000 feet (2,700 meters) or more. It was more narrowly limited and defined by the orogenic uplifts of the mountain ranges, which, according to the evidence of fossil plants, cannot be dated farther back than the early Miocene.

PUGET SOUND AND THE STRAITS

Puget sound lies in the northern part of this trough. The application of the name has been variously defined. Vancouver originally gave it to the sound explored by Lieutenant Puget on a boat trip, and which is a branch of Admiralty inlet, beginning at the south end of Vashon island and extending thence south and west. As now almost universally used, the term includes all of Admiralty inlet, and is defined in the Pacific Coast Pilot in the broad acceptation of the term as lying between latitudes 47° 03′ and 48° 11′ and between longitudes 122° 10′ and 123° 10′. The latter definition does not appear to extend to Hoods canal, an important member of the system, but in the phrase " Puget Sound basin " in this article the name is intended to cover all that complex maze of channels south of the strait of Juan de Fuca. Southeast of Vancouver island is an indefinite water body defined by the United States Coast Survey as the eastern end of the strait, which thus extends to Whidbey island. Puget sound opens from it. Vancouver called the eastern part of the strait part of the gulf of Georgia, but his usage has not prevailed.

Classification of Topographic Features

The topographic features of the Puget Sound basin are readily classified by magnitude as major and minor. The major features are (1) elevated plains or plateaus and (2) hollows long, narrow, and deep. The relations of these two classes are simple: The hollows surround the plateaus which are thus islands, except on the extreme eastern and western sides of the basin where the plateaus form elevated benches along the foothills of the adjacent mountains. To enumerate types there are of islands: Whidbey island, the Great peninsula, Vashon island, and Des Moines island; and of hollows: Hood canal, Admiralty inlet, Duwamish valley, and Puyallup valley. The minor features of the region are of three genetic classes, namely, (*a*) features due to constructive ice-work, (*b*) features due to constructive water work, and (*c*) features due to destructive water work. In the following table the several types are specified.

a.	*b.*	*c.*
Features due to constructive ice work generally aided by water.	Features due to constructive water work.	Features due to destructive water work.
Undulating till plains........	Gravel plains...........	Stream terraces.
Osars and kames............	Delta terraces...........	Ravines.
Moraines....................	Alluvial cones...........	Cutbanks.
Kame terraces	Alluvial plains.........	Sea-cliffs.
Lake basins.................	Marshes.................	Wave-cut terraces.

A common topographic feature which does not come under any of the above types is the landslip, scarp, and terrace, which frequently simulates, modifies, or destroys other topographic individuals.

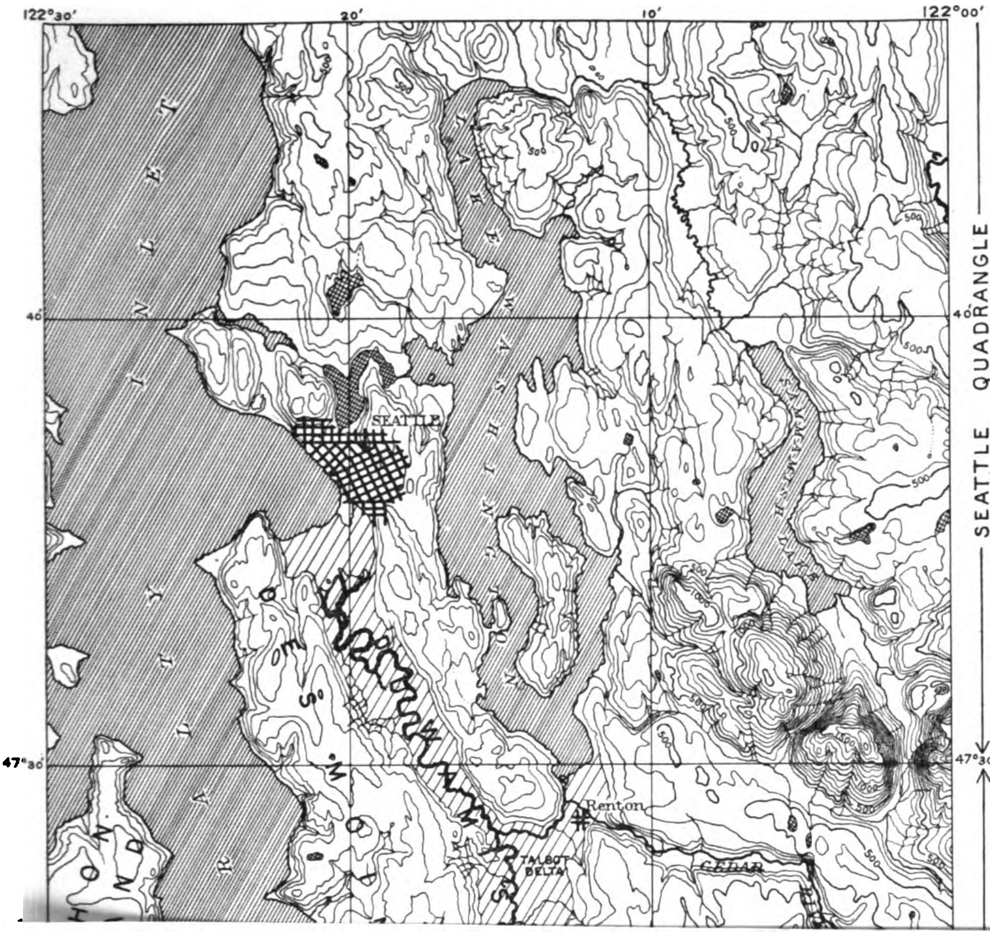
Description of the major topographic Features

PHYSICAL CHARACTERS IN GENERAL

Within the region of Puget sound the topographic forms of greater magnitude are determined by masses of stratified and unstratified drift, whichconstitute the islands. Water and alluvium occupy the interspaces or hollows. Outcrops of the underlying rocks of Cretaceous and succeeding periods are rarely visible. The minor topographic features are carved in the drift masses or modelled on their surfaces. To the north and northwest the San Juan islands and Vancouver represent a height-of-land in which hard rocks more generally rise above the drift.

PLATEAUS, THEIR DISTRIBUTION AND CHARACTER

The major elevations of the Puget Sound basin are of the plateau type. They are essentially flat topped and are bounded by steep slopes descend-


122°30′
20′
10′
122°00′
40′
47°30′
SEATTLE
Renton
TALBOT DELTA
CEDAR
SEATTLE QUADRANGLE

ing abruptly to alluvial plains and to the waters of the sound. As benches along the mountain spurs they fringe the Cascade and Olympic ranges up to 1,200 feet (360 meters) above sea, locally. Toward the axis of the sound their altitudes vary from 400 to 500 feet (120 to 150 meters) above sea. In any one district they are approximately of uniform height, and viewed as a whole constitute the surface of the vast drift mass with which the basin is partially filled.

There is no map which satisfactorily represents the distribution of these plateau-shaped masses. Their boundaries against the Cascades and Olympics have not been surveyed. Their outlines as defined on the charts of the sound are incomplete, since the coastline extends from one mass to another wherever the intervening hollow is filled with alluvium instead of water. Thus Des Moines island is merged with the mainland, although physiographically it is isolated by the Duwamish valley, which is the homolog of Hood canal. The northeastern extremity of the Olympic peninsula is divided by a similar depression which connects Hood canal with the strait of Fuca. The Great peninsula is likewise separated into island-like masses by lowlands which connect the reentrant bays.

The plateau masses between the mainland on the east and the mainland on the west, thus isolated by depressions filled with water or alluvium, are of long and narrow forms, with major axes trending north and south in general. The trends are not uniform, however. On the west they diverge southwestward and on the east they depart southeastward, giving the sounds a pear-shaped form, of which the entrance to Admiralty inlet is the stem.

The margins of the plateaus along the tops of the slopes are wavy, but in details entire, in the sense that the edge of a leaf is said to be entire. They are but rarely and not deeply incised by streams. The outlines along the slopes at water level have been modified by waves, which have cut away portions and built out spits.

THE HOLLOWS, THEIR DISTRIBUTION AND CHARACTER

Interrelations.—Admiralty inlet extends from the southeastern end of the strait of Fuca 58 miles (93 kilometers) south by east, with an average width at sealevel of 3.5 miles (5.6 kilometers). It is the trunk of an unsymmetrical labyrinth of hollows, which ramify 40 miles (64 kilometers) in a course of south by west, with a width of but 1.5 miles (2.4 kilometers). Duwamish valley is the southeastern member. It trends southeast and south 35 miles (56 kilometers), and is about 2 miles (3.2 kilometers) wide. It is partially filled with alluvium. Between Admiralty inlet and Hood canal are many hollows, locally deeper than sealevel, and elsewhere shallower, forming inlets and valleys. Their typical relation is that of the stem and arms of a Y or of one inverted, ⅄. They branch both northward and southward, the branches connect, and they thus enclose a number of irregularly polygonal areas, whose relations suggest a curious mosaic. The deepest axes of the hollows are delineated on plate 6, which also expresses by interrogation points the existing doubt as to some of the connections across land areas.

Variations of depth.—The depths of the hollows are peculiarly distributed. Specific figures taken from the United States Coast Survey chart are given in plate 7, and gradations of depth for each 50 fathoms (91.4 meters) are indicated in plate 6 by the character of the line which follows the channel. All depths are referred to sealevel, which is a datum not genetically related to the topographic form. The true depth of the hollows should be measured from the plateau level, and therefore from 400 to 500 feet (120 to 150 meters) or, say, 75 fathoms (137 meters) may be added to the figures on plate 7.

Admiralty inlet is relatively shallow at its northern end; opposite Admiralty head the depth of water is but 46 fathoms (84 meters), and the bottom is rocky. Shoal water extends thence northwest into the strait of Fuca, it being 12 miles (20 kilometers) to the 50 fathom (91.4 meters) contour. Toward the southeast the channel deepens rapidly. Five miles (8 kilometers) from Admiralty head the sounding is 104 fathoms (190 meters); about midway of the length of the inlet north of Seattle occurs the maximum depth of 153 fathoms (280 meters), and thence almost to Tacoma the figures are not less than 95 fathoms (143 meters). From Admiralty head south to Tacoma the bottom is described as coarse sand, fine sand, and mud. These facts indicate that along the line of this hollow for 60 miles (96 kilometers) the hard rock bottom slopes southward. For half the distance the descent is 600 feet (183 meters), carrying the bottom on mud down to 900 feet (274 meters) below tide. If the slope continues at the same rate, bed rock at Tacoma is not less than 1,500 feet (457 meters) below sealevel.

Profiles of Admiralty inlet and Hood canal.—A cross-section of Admiralty inlet is given in figure 1. The locality selected is one exhibiting the

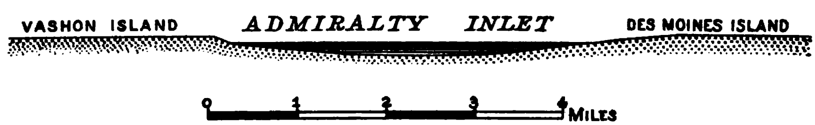


FIGURE 1.—*Section across Admiralty inlet just South of Point Pully.*

average relations of width and depth. The section extends from the Des Moines island on the east to Vashon island on the west, a distance of 4 miles (6 kilometers) between shores, and the maximum depth is 127 fathoms (228 meters). The U. S. Coast Survey soundings and the contours on the U. S. Geological Survey map of the Tacoma quadrangle give the profile. Whatever the original profile may have been, the existing one is a modified form. Above sealevel it presents the scarps of sea-cliffs, which are probably steeper than the earlier slopes; at sealevel is a wave-cut bench; below sealevel the slopes are probably subdued by the effect of landslides and by deposition. The relation of height of profile to width is thus shown to be strikingly moderate.

In the following table the ratios of depth to width are given for a number of representative localities. Admiralty inlet is shown to be relatively deeper in its southern portion, the narrow arms of its southwestern branches (the Puget sound of Vancouver) are relatively deeper still, and Hood canal is relatively to its width the deepest of the hollows. The ratio ranges from 1:12 in Hood canal to 1:72 at the northern entrance to Admiralty inlet.

For Admiralty inlet and Puget sound south of point Defiance.	Depth.		Width.		Ratio.	Nature of bottom.
	Fathoms.	Meters.	Miles.	Kilometers.		
Point Wilson to Admiralty head	46	84	3.75	6	1:72	Rocky.
Foulweather bluff to Double bluff	64	114	3.125	5	1:43	Sand and gravel.
Point Jefferson to east shore	153	280	4.375	7	1:25	Coarse black sand.
Vashon island to point Pully,	125	232	3.125	5	1:21	Green mud.
Point Robinson to Buenna	99	150	3.75	6	1:40	Gray mud.
Point Defiance to Vashon island	37	67	1.25	2	1:29	Gray sand and gravel.
Steilacoom to McNeil island	100	183	2.5	4	1:22	Gray mud.
For Hood canal.						
Hood head to east shore.	73	133	1.25	2	1:15	Gray sand and mud.
Quatsap point to east shore	88	161	1.875	3	1:19	Mud.
Aycock point to east shore	88	161	1.25	2	1:12	Fine gray sand.
Middle of northeastern spur	22	40	.9	1.5	1:37	Rocky.

The proportions stated in the preceding table may gain in significaenc by comparison with more familiar examples of similar cross-section. The following are the ratios for the Hudson river, in New York, and the Sogne fiord, in Norway:

Hudson river, New York.	Depth.		Width.		Ratio.
	Fathoms.	Meters.	Miles.	Kilometers.	
Fort Washington point to west shore...........	24	44	.75	1.2	1:50
West Point to Constitution island..............	36	66	.188	.3	1: 4.5
Anthonys Nose to west side....................	22	40	.31	.5	1:13

Sogne fiord, Norway.	Depth.		Width.		Ratio.
	Norske fathoms.	Meters.	Norske miles.	Kilometers.	
At the entrance....	50	94	.4	5	1:53
4.6 Norske miles (51.5 kilometers) from the entrance..	661	1,242.7	.3	3.4	1: 2.8
5 Norske miles (56 kilometers) farther inland...	511	960.7	.5	2.6	1: 2.7

The Hudson river is deepest at West Point, where also it is narrowest, and the bold mountains on either hand give it the character of the Norwegian fiords. At this point it more nearly approaches the Sogne fiord in relative depth than even Hood canal. Both above and below this narrow canyon the wider reaches of the river shallow to less than 10 fathoms (18 meters). The depth appears to be determined by the effects of deposition and scouring, and affords no measure of the preglacial depth of the canyon.

The Sogne fiord has soundings of more than 650 fathoms (1,190 meters), and the mountains on either shore rise precipitously to 2,500 feet (760 meters) above the sea. At its entrance the canyon is partially filled by a terminal moraine, whose height is indicated by the great depths which prevail but a short distance farther in.

The Norwegian fiords differ from the inlets of Puget sound in being features of hard rock topography, modified by drift deposits only on the bottom. The Puget Sound hollows are excavated in or built around by drift, which almost completely buries the antecedent topography.

HYPOTHESES OF GENETIC PROCESSES

General statement.—The Puget phase of the fiord type may probably be related to the Norwegian phase as genetically similar, with excess of glacial deposition over antecedent topographic relief in the Puget basin. This idea is consistent with two hypotheses of the origin of the hollows and plateaus, which may be stated as follows:

The erosion hypothesis.—As a result of general glaciation the Puget Sound basin was filled with drift to an approximately even plain. With retreat of the ice after one or several epochs of glaciation, streams were established, which cut their channels in the drift down to a level represented by the depths of the Sound. In consequence of depression of the region the valleys were submerged and the present inlets established.

The construction hypothesis.—Glaciation of the Puget Sound basin was confluent, not indigenous. The distinction is important in its bearing on the effects of advance and retreat of the ice. Where glaciation is indigenous the accumulation begins at high altitudes, and the summits are covered with névé before the lower valleys are filled with ice. In the epoch of lessening glaciation the summits are last bared. But where glaciers become confluent in a region in which they do not originate the valleys are first occupied and filled and the hills are subsequently buried. When the ice-mass diminishes, the hilltops are laid bare while yet the valleys are the seats of glaciers. Glaciers first occupied the valleys of the Sound basin, but becoming dammed rose till the ice overtopped divides. During the episode of retreat hilltops appeared as nunataks, and this condition extended to divides. In ponded waters about these nunataks accumulated stratified drift. Stagnant ice lingered in the valleys to the latest stages of retreat, and, melting, perpetuated the hollows. By repetitions of this process the antecedent divides were built out to plateau forms and the axes of the original valleys were maintained as relatively shallow hollows, which are thus the casts of glacial tongues. Oscillations of level and the effects of erosion played a subordinate part.

The erosion hypothesis is based upon analogies with fiords and estuaries of other coasts. The construction hypothesis was first suggested to me by Russell upon the analogy of the Malaspina glacier. I received it with doubt, but detailed field work has tended to confirm and elaborate it.

Description of minor topographic Features

ORDER OF TREATMENT

The topographic features which are characteristic of the drift-covered region of the Puget Sound basin are related in a sequence composed of several groups to which successive dates may be assigned. The processes now going on have been continuously in operation since the ice last retreated. They define an episode, the latest, but their effects have differed locally according to the position of sealevel. It is possible to discriminate two incidents, the one related to the present attitude of land and sea and the other to a previous attitude of deeper submergence. The next antecedent episode is defined by the conditions of the last glacial retreat, and preceding that retreat was the epoch of the last glacial advance and occupation. These three episodes, which include the history of the region from the present time back to the last general episode of glaciation, are recorded in details of topographic forms.

THE PRESENT AND ITS IMMEDIATE ANTECEDENTS

Method of presentation adopted.—In discussing this portion of the subject, it will be convenient to consider in their natural order the effects of corrasion by streams, of deposition from streams, and of wave work.

Ravines and canyons.—Green river is a stream rising in the Cascade mountains and flowing westward. It enters the Duwamish valley at the same point as White river, a little north of east from Tacoma. Its upper course in the mountains is a canyon with very steep but generally not precipitous slopes, heavily covered with forest. From this canyon it debouches on an extensive gravel plain, across which its course extends about 20 miles (32 kilometers) to the Duwamish valley. In slightly less than half this distance it sinks below the level of the gravel plain in a canyon which is approximately 200 feet (60 meters) deep. In cross-section the higher slope of this canyon is banked with gravel terraces. The lower part, one-third to one-half the total depth, is cut across tilted strata of sandstone and shale which very moderately resist corrasion and exfoliation. The lower walls, where of sandstone, are precipitous and often overhang. The superficial gravel of the plain is to a large extent pebbly till, but the date of the glacier which spread it has not been exactly determined. If it corresponds to the last general expansion of the ice in the Sound basin, as is probable, the canyon represents the extent of corrasion since the final retreat. The river drains an area of 250 square miles or more (64,800 hectares) in the Cascades and is a vigorous stream throughout the year. It still falls rapidly through its lower canyon.

Carbon river heads in a glacier on mount Rainier, from which it flows in a northwesterly course to the Puyallup valley. Its waters are milky with glacial meal, and it sweeps along quantities of fine sand. Its volume and rapid fall and sufficient abrasive material render it an efficient agent of corrasion. Its valley is readily divided in three sections, which differ in age and topographic forms. The upper heads in a huge amphitheater on the northern side of mount Rainier, and its extremity is occupied by a glacier four miles in length. The amphitheater and canyon leading from it are shut in by precipices from 1,000 to 4,000 feet (300 to 1,000 meters) in height, composed of andesites of the great Tertiary volcano. Where this uppermost section of the valley, 16 miles (25 kilometers) from the present end of the glacier, passes into a series of Eocene sandstones and shales it widens notably, the slopes recede, and tributaries enter the river from the south. In this lower part of the uppermost section the river is bounded by a terrace approximately 60 feet (20 meters) above its present level. The terrace bench is of sand and gravel, with occasional large boulders resembling closely the material now deposited by the swift but overloaded stream, but underneath the river deposit lies an old lateral moraine which marks the former expansion of the existing glacier to a point 20 miles (32 kilometers) below its present end. This old moraine was discovered in driving a tunnel into the terrace for the purpose of opening the coal measures at the lowest available level. It is composed of the heterogeneous accumulations typical of morainic debris, including massive rocks up to 6 or 8 feet (2 to 2.5 meters) in diameter. The total length of the upper section of the river from the amphitheater in mount Rainier to where it narrows at its lower end is 20 miles (32 kilometers).

The second section of the river is a steep sided canyon 5 miles (8 kilometers) in length, through which the stream passes in a series of rapids. The canyon walls are of Eocene sandstones and shales, with some intrusive volcanic rocks. They are frequently perpendicular to heights of 200 feet (60 meters) or more, and are crowned by steep slopes covered with gravel and sand up to a total height of 500 feet (153 meters) above the stream. In the upper 3 miles (5 kilometers) of its course through this canyon, the river receives no tributaries, and a swamp which lies 500 feet (153 meters) above it on its eastern side is drained away from the river by a small creek. Carbonado is situated on the lower part of this canyon section, at a point where the stream turns from a northerly course to northwest. At this point, 400 feet (122 meters) above the present channel, there are older river courses continuing to the north and eastward and intimately related to the positions of the ice front during the latest general glaciation of the sound.

The third section of the river valley belongs to the Puyallup valley, one of the great hollows of the Puget Sound system, whose age and origin are at least open to discussion.

Thus it is obvious that the valley of Carbon river consists of an upper section which dates back to the inception of glaciation upon the Tertiary volcanic cone, and which has been completely occupied during the glacial period by an ice-tongue from the mountain. In its latest phase this glacier exists at the head of the canyon. The second section was apparently determined in its course by the accidental relations of glaciers, whose recession both to the southeast and northwest opened the way for its flow. It first pursued a channel in the drift, and in post-Glacial time has cut its canyon 200 feet (60 meters) into the coal-bearing strata and associated igneous rocks. It now enters the Puyallup valley at a point somewhat remote from courses which it pursued during the earlier part of the episode of glacial retreat.

The two rivers described represent cases of streams rising outside the area of extensive drift and flowing into it. They are well supplied with abrasive load and cut rapidly. Their canyons give a maximum measure of postglacial corrasion. Cases of another degree are found in brooks which rise within the plateaus and descend to the alluvial plains in the major hollows. Such streams have their courses wholly within the drift, their waters accumulate in swamps, and their power of abrasion is practically *nil*. They cut ravines in steep slopes, however, where they flow in such manner as to undermine the gravel banks.

Fennel creek is a brook draining about 8 square miles (2,000 hectares) of swamp in the Tacoma quadrangle and emptying into the Puyallup river. The course from the swamp to the alluvial plain is 4 miles (6.4 kilometers); in this distance the brook falls 400 feet (122 meters), and seven-eighths of the total fall is concentrated in the lower mile and a half (2.4 kilometers). The head of active corrasion is where this rapid descent begins, and is marked by a cascade 40 feet (12 meters) in height. The valley of the brook is determined by an interglacial delta facing northward and westward, around whose base it flows, and by a gentle southward slope of till on which lie the swamps. The depression in the plateau surface is therefore of glacial age, and the effect of postglacial corrasion is represented in the ravine below the fall. The ravine is a notch in the steep slope from the plateau to the alluvial plain. The maximum depth of the ravine below, a contour restored in its probable former position, is 150 feet (45 meters), and the channel at the level of that contour has receded three-fourths of a mile (1.2 kilometers). The section thus far cut has the outline of a very low obtuse-angled triangle, with the stream on the long side. The work accomplished by Fennel creek is a fair example of postglacial dissection of the plateau margins. The ravines of this type are as yet cut only in the margins; the interiors of the plateaus are not dissected, but are diversified by lakes and swamps.

Flood plains and deltas.—At their debouchures from the marginal ravines of the plateaus, those streams which enter alluvial plains build cones, and those which empty into tidewater tend to construct deltas. The alluvial cones are generally composed of gravel and coarse sand. They are of moderate size and are noticeable chiefly as areas of material coarser than the alluvial silt with which they merge.

White river, a stream draining the largest glacier system of mount Rainier and entering the Duwamish valley nearly due east of Tacoma, presents peculiar features of alluvial accumulation and stream adjustment. At a point in its gravel-banked gorge 2.5 miles (4 kilometers) east of the eastern edge of the Duwamish valley the river divides into two branches, which continue on distant courses, known as White river and Stuck river, to tidewater, and empty 23 miles (39 kilometers) apart. For 2 miles (3.2 kilometers) from their parting the branches diverge but slightly; but thence the one flows northward to Elliott bay near Seattle, whereas the other, Stuck river, turns southward and, joining the Puyallup, discharges into Commencement bay opposite Tacoma. Des Moines island, which is shown on the map, plate 7, lies between the two mouths. The point of divergence is about 160 feet (48 meters) above tide. The distance to the northern mouth at Seattle is 23.5 miles (37.6 kilometers) along the axis of the valley and 37.5 miles (60 kilometers) by the river's course. By the southern branch to the Puyallup is 8.5 miles (14 kilometers) along the valley's course, and to the delta front in Commencement bay 16 miles (25 kilometers). Both northward and southward the Duwamish valley is filled with alluvial silt, such as the White and Puyallup rivers now carry from the glaciers and with which they are extending their deltas. Throughout their courses White and Stuck rivers flow between steep banks of alluvium, 5 to 15 feet (1.5 to 4.5 meters) high above the average water level of the streams and slightly higher than the plain toward the sides of the valley, where marshy ground occurs. Thus the streams meander through typical flood plains. The topographic type represented by the divergent arms of White river and their flood plains is that of an alluvial cone merging into a delta, recognizable as a simple, consistent form when traced up from either mouth to the parting of the arms, although they embrace the older feature, Des Moines island.

From the head of the alluvial cone, where the arms separate, to the deltas this peculiar river formation is at the present time in vigorous development. It is nowhere yielding, but in each phase is growing. From the data on the topographic map its slopes have been determined as follows:

Distances between determined Elevations.

Elevations.		White river.				Stuck river.			
		By river.		On the plain.		By river.		On the plain.	
Feet.	Meters.	Miles.	Kilo-meters.	Miles.	Kilo-meters.	Miles.	Kilo-meters.	Miles.	Kilo-meters.
160–100	48.7–30.5	3.25	5.2	2.5	4	3.5	5.6	3	4.8
100– 50	30.5–15.3	10.25	16.4	6	9.6	6.5	10.4	5.5	8.8
50– 0	15.3–0	24	38.4	15	24	10.5	16.8	7.5	12

From these measurements it appears that the fall per mile (1.6 kilometers) of White river in the three sections is, in round numbers, 15, 5, and 2 feet (4.5, 1.5, and 0.6 meters), respectively. These grades are very steep, but the river is aggrading and not degrading the form, because it always carries an excessive load. The cone is growing upstream by the addition of coarser material at its head. As its slope is thus raised the gravel and sands previously deposited on its surface are swept further down by the current, which is accelerated. Lower down the finer silt is moved by stages in a similar manner, coincidently with the building up of the cone, but where the slope passes below tide the construction is that of a delta terrace with a relatively bold front which descends into deep water.

This topographic form is very delicately adjusted to sealevel. If by regional movement it should be lifted higher than its present attitude, the cone would be dissected by the river from the mouth retrogressively and would be represented in the readjusted topography by terrace remnants. There are no such fragments of any older cone in the Duwamish and Puyallup valleys, and their absence indicates that there has been no uplift from an attitude of greater depression during which the conditions of alluvial deposit were similar to those of the present. If, on the other hand, the land were appreciably more deeply submerged, the delta terrace would extend beneath the sealevel as a broad shoal, upon which at some distance back from its earlier front a new delta would be built up. The United States Coast Survey charts show that the deltas are now being extended into water which deepens rapidly from 1 fathom (1.8 meters, at the delta's edge to 50 fathoms (90 meters) three-fourths of a mile (1.2 kilometers) out, and which continues to deepen to 100 fathoms (183 meters) or more. From this fact it follows that any subsidence of the land which may be going on is progressing at a rate which is less than that of the counterbalancing process of delta-building.

The alluvial cone and deltas of the White River system, filling the Duwamish valley and extending to the Puyallup valley, are thus seen to be indicative of stability of sealevel during the epoch of their development. This epoch is postglacial. Its duration may perhaps be estimated within fairly close extremes if the rate of delta expansion shall be determined for both Elliott and Commencement bays. There is independent evidence which might appear to contradict the inferred stability of sea-level, and which consists in cut terraces and small deltas of brooks occurring at some height above sea. These features were pointed out by Russell, who at the time interpreted them as records of post-Pleistocene submergence and uplift marked by two terraces, one at approximately 80 feet (20 meters), the other at 20 feet (6 meters) above the present sea-level. Observations made subsequently in the Duwamish valley indicate that the terraces above 60 feet (18 meters) are records of ponded waters which gathered during the epoch of latest glacial retreat. I shall discuss them more fully in that connection. The terrace at 20 feet above sea is probably wave-cut and records an uplift of that amount.

Sea-cliffs and benches.—The shores of the Sound generally present bold profiles, which in some instances result from landslides, but more extensively are sea-cliffs. The heights of the cliffs are functions of the steepness of the original slopes in which the facets are cut. They vary from 10 feet (3 meters) to 300 feet (90 meters). The bench extending from the bases of the cliffs out below tide is defined by the steeper grade, which begins at a depth of 1 to 2 fathoms (1.8 to 3.6 meters). It varies in width from 150 feet (45 meters) abreast of the promontories to 1,000 feet (300 meters) or more in the little bays. Off the headlands the bench is probably for nearly its full width cut into the drift slope; in the bays it is largely or wholly built out. Spits and bars of characteristic forms also occur along the shores, but the great depth of the waters and the slight power of the waves render the growth of such features extremely slow.

FEATURES OF THE EPISODE OF LATEST GLACIAL RETREAT

Nature of glacial accumulation.—Before proceeding to any description of the drift phenomena it is necessary to state a conclusion which follows unequivocally from several lines of evidence. The Puget Sound basin was repeatedly occupied by glaciers flowing from three directions, namely, from the east, from the west, and from the north. The western system descended the short eastern slope of the Olympic range, and having but a limited area of accumulation was probably of least volume of the three. The eastern system occupied the valleys in the western slope of the Cascade range from the Skagit valley to the Cowlitz valley. It was larger in area than the western system and included the glaciers of mount

Rainier, which still present fine examples of the alpine type. The northern system descended from the district of the San Juan archipelago. It was the southern tongue of the confluent ice-mass which, gathering on the Cascades in British Columbia, filled the gulf of Georgia, whence its main body discharged westward into the straits of Fuca. That portion which presumably flowed northward past Vancouver island is not considered here.

The southern tongue of the northern ice-mass or the northern system of the Puget Sound basin was far larger than the western and eastern systems. From the highland of the San Juan district it pushed between them southward beyond Tacoma and even up the Puyallup valley to Carbonado, where its marginal effects are to be seen at an elevation of 1,600 feet (488 meters) above sealevel. It thus intruded into the territory of the Rainier glaciers, which were not permitted to extend more than 25 miles (40 kilometers) northwest from that mountain. The overpowering volume of the northern ice as compared with that from the west and east is a fact which explains many peculiar features of the distribution of drift and which bears directly on the origin of the topography.

Throughout this article the name Vashon will be given to the episode represented by the latest occupation of the Puget Sound basin by the northern ice-tongue and its deposits. The term is derived from Vashon island, where the gravelly till characteristic of the episode occurs typically, although not heavily. No correlation with any area beyond the limits of the Tacoma and Seattle quadrangles is attempted in giving this name, which is chosen to avoid the confusion arising from such terms as upper and later when comparisons with other regions become necessary.

A lobe of the Cascade glacier opposed the Vashon glacier in the eastern part of the Tacoma quadrangle. It spread a characteristic till on the plain on which is situated the hamlet of Osceola. This lobe of the Cascade glacier and its till will be accordingly designated Osceola lobe and Osceola till.

The topographic features due to the Vashon Glacier system can now be described. Those which belong to the more recent vanishing stage of retreat will in general be treated first, but the chronological order cannot be rigidly adhered to where several features of one kind developed during successive stages.

Lateral moraines.—The slopes which bound the Duwamish valley on the east and west are steep and generally clothed with forests. Not having been subjected to the action of waves, they retain minor features which in the cutting of sea-cliffs have been obliterated along the shores of Admiralty inlet. These features are of glacial origin and record several stages of the latest glacial episode.

On the western side of the Duwamish valley, 3 miles (4.8 kilometers) north of Kent, the slope which rises from the alluvial plain curves southwestward from a projecting promontory. Within this curve the slope is 350 feet (100 meters) in height, and is diversified by a group of peculiar ridges. The ridges lie upon the slope and trend south at an angle to the direction of steepest descent. They occur in groups of two or more, which are roughly parallel, but which coalesce at points along their course, forming enclosed kettles. They are 40 feet (12 meters) or more in height and from three to five times as long as they are wide. Their southeastern slope is steeper than the northwestern, and their crests descend from the point of contact with the hill above toward the south. They are composed of clayey gravel, sometimes heterogeneously mixed and again stratified. Large boulders may be seen, but do not form a prominent feature. The distribution of these small ridges extends from the point of the promontory on the north along the convex side of the embayment for a distance of 3 miles (5 kilometers) to a point nearly west of Kent. The ridges are homologous in form, position, and material to certain lateral moraines, which can be seen on mount Rainier in their true relation to the Carbon River glacier at the present time. They constitute a record of the lateral shrinking of that tongue of the Vashon glacier which followed the Duwamish valley and still occupied the space between the plateaus in the latest stages of its retreat. These ridges are older than the alluvium beneath which they disappear.

At a point 16 miles (25 kilometers) south of the above-described locality, on the eastern side of the Puyallup valley, the escarpment of the plateau presents features of glacial construction. At an elevation of 400 feet (120 meters) above the valley a ridge one-quarter of a mile (400 meters) in length extends from point to point of the plateau slope, enclosing between it and the plateau several hollows. The ridge is so narrow and even as to resemble a huge embankment. The kettles behind it are 60 to 100 feet (20 to 30 meters) in depth and of unusual size. At its southern end the ridge constitutes a promontory, with a very steep southern slope. In a section exposed by a road grade on this declivity the relation of the ridge to the plateau mass can be seen in section. The ridge is composed of coarse and fine gravel and sand, with large boulders. The mass of the plateau at the level at which the section is exposed consists of fine sands, which are horizontally stratified and are recognizable as one of the older Pleistocene formations traced throughout the Puyallup valley. The contact plane between the moraine material and the sands dips 60° to the west toward the valley. It is undisturbed, and clearly a plane of deposition and not a landslide fault plane. The relation of this ridge to the plateau mass is thus seen to be indicated in its form and in cross-section as that of a lateral moraine built across a reentrant angle in the banks which confined the glacier.

The two instances described are the more striking occurrences of features traceable throughout the Duwamish and Puyallup valleys, so far as their banks have not been modified by landslides or by the lateral corrasion of the streams. These features demonstrate the fact that the valley was occupied by a glacier, which in retreat shrank into the hollow to depths which now lie beneath the modern alluvial cone.

In the plateau, 2 to 4 miles (3 to 6 kilometers) east of the Duwamish valley, a channel extends from near Cedar river south by east for 7 miles (11 kilometers). It is occupied by swamps, through which meanders Big Soos creek. Its bottom is between 300 and 400 feet (91 to 122 meters) above sea. It is one-eighth to one-quarter of a mile (.2 to .4 kilometers) wide, and its slopes are steep embankments 100 to 150 feet (30 to 45 meters) high. At several points along the course of this hollow narrow ridges are built diagonally along the steep slopes. They are of coarse material, including large erratics of granite. They also are lateral moraines, which indicate that this hollow existed before the latest ice advance, and that during the last retreat from this area it was occupied by a glacial tongue after the general surface of the plateau was cleared.

Evidence of a similar kind, left by a glacier which followed the valleys from the southeast, is to be found on South Prairie creek, in the vicinity of South Prairie. One striking instance which occurs just west of the main road from South Prairie northwestward to Sumner is a small hill about fifty feet (15 meters) in height and 100 yards (90 meters) long, standing immediately on the margin of a gravel terrace. The terrace is 200 feet (60 meters) high above the valley, and the hill is a dump heap of morainal material deposited from a glacier which occupied the valley.

Deltas at low levels.—The features to be described under this head have been observed between Renton and Kent, along the eastern bank of the Duwamish valley. They are of limited occurrence. Their absence at the same levels elsewhere is due in part perhaps to their removal as the larger rivers cut away the slopes, and in greater part to the non-occurrence of conditions favorable to their development.

The Talbot delta is an alluvial form, herewith named from the old Talbot coal mine which was worked out beneath it, a mile and a quarter (2 kilometers) south of Renton. On its eastern side Eocene sandstones crop out in the plateau slope at 200 feet (60 meters) above sea; its western margin is even with a bold bluff of similar sandstones which stands above the White river flood-plain at an altitude of 175 feet (53 meters) above sea. Between these outcrops lies the mass of sands 3,000 feet (915 meters) across from east to west. Its surface descends northward with moderate slope. Along its eastern side a small brook has cut a gulch. Three levels may be recognized in this form. The lowest is an ill defined bench 40 feet (12 meters) above the flood-plain of White river and about 65 feet (17 meters) above sea. From it the slope to the marsh below is 15 degrees. The terrace is composed of reddish brown sands of medium grain apparently derived from the Eocene sandstones, with small pebbles from the drift. The lobe is strongly convex toward the northwest. From the lowest bench the surface rises gradually for 100 yards (90 meters) to a second terrace edge at about 95 feet (30 meters) above sea. This level is much more extensive than the lowest bench; it is composed of the same materials, and represents a similar formation in deeper water. The alluvial plain rises very gently and uniformly southeastward to the third and highest flat, which is about 180 feet (55 meters) above sea. Sparsely distributed over the delta are boulders, generally of granite, which range up to 4 feet (1 meter) in diameter.

This delta was produced by the stream which now flows along its northern edge. The water body in which it accumulated changed in depth during the growth of the delta. As the lower features are partly buried and the higher levels are not dissected, it is inferred that the water rose gradually and was subsequently rapidly lowered in such manner as to concentrate the stream on the eastern side. The boulders on the surface indicate the presence of floating ice.

From the Talbot delta southward to Kent the eastern bank of the Duwamish valley presents features for which the delta is a convenient reference. East of Kent a remnant of a delta terrace borders the foot of the slope on the southern side of a gulch. Its surface rises from about 70 feet (22 meters) above sea at the margin to 90 feet (27 meters) at the back. The brook which built it cut it through the middle.

Nearer the Talbot delta the brook flowing from Panther lake has produced a deposit of sands of faintly marked delta-form, but much obscured by forest and dissected by the brook. The sands extends northward for some distance along the slope as a nearly level flat a little less than 100 feet (30 meters) above sea. Spring brook, a small stream a mile (1.5 kilometers) south of the last described locality, has produced and bisected a cone of coarse gravels whose apex is 135 feet (41 meters) above sea, and whose lower portion may probably have been a delta corresponding to the Talbot delta at the lower levels. Between Spring brook and Kent a larger brook debouches into level meadows from a narrow ravine in an embayment in the slope. It does not possess an old delta. Across the embayment three remarkable ridges are thrown in parallelism. They rise 15 to 75 feet (4 to 23 meters) above the valley, are sharp crested, and composed of cross stratified sands and clays with occasional boulders. They probably represent accumulations in channels beneath the ice. The absence of a delta corresponding to the Talbot delta may be accounted for by the assumption that the stream flowed out upon the ice and any deposits dropped as it melted.

Benches in the hard rocks occur south of the Talbot delta and as far south as the outlet of Panther lake. They antedate the terraces in glacial and glacio-fluvial deposits, as the latter rest upon them. In hard rocks in close proximity to ice gentle slopes tend to extend as flats and steep slopes to become precipices under the action of frost. The rocks of the Puget Sound basin were long subjected to such sculpture, and these benches may with probability be classed as effects of that phase of glacial carving. The presence of large blocks of Eocene lignite in till south of Kent shows that the Eocene rocks were exposed to glaciation.

The evidence derived from the study of the deltas and their allied forms along the slope of the Duwamish valley indicates that during a late phase in the retreat of the Vashon glacier the valley was occupied, along its eastern side at least, by waters ponded by the ice. The absence of deltas on the western side cannot be positively asserted, but none were observed. Their development may have been prevented by ice along that bank or limited by the fact that the drainage of the plateau is away from the valley to the southwest. The extent of the ponded waters has not been determined. It may have included the Puyallup valley and a section of Admiralty inlet.

Deltas at high levels.—Between White river on the northeast, South Prairie creek on the south, and the Puyallup river on the west is a triangular plateau mass of complicated structure, which has a general elevation of from 500 to 600 feet (150 to 180 meters) above sealevel. Its apex points toward the northwest and its eastern level extends beyond White river northeastward. In its northwestern apex the surface of the plateau is diversified by long narrow ridges and lakes, which will be described as marginal features of the Vashon glacier, produced during a long pause in its retreat. They antedate that vanishing phase when it had shrunk to an ice-tongue in the Duwamish valley and deposited the lateral moraines already described. Across its central section from northeast to southwest this plateau mass is lowest and has a gentle southern slope. Its surface is now a swamp, underlain by till characteristic of the region to the eastward and attributed to a glacier which descended from the Cascades. This till will be referred to as the Osceola till, as that hamlet lies in its widest expanse. Fennel creek drains these swamps. On the east and south the low marshy level is bounded by a well defined terrace about 100 feet (30 meters) in height. The northern slope and margin of the terrace are not regular, but exhibit inequalities of level of 10 to 40 feet (3 to 13 meters). A short distance back from the margin, however, the surface becomes an even plain, with gentle northern slope, and extends to the south and southeast with monotonous character for from 2 to 4 miles (3 to 6 kilometers). Near its northern margin this terrace is composed of sand and fine gravel, which are stratified. Further south the gravel gradually increases in proportion and boulders up to 1 foot (.3 meter) in diameter appear upon it. The materials, the terraced form, and the stratified structure identify this feature as a delta formed by streams flowing in from the southeast and south. The relations to existing drainage indicate that the delta is a composite one, derived from the older representative of White river and the corresponding ancestor of Carbon river, and the delta plain is divided north and south by a slight swampy depression which marks the limits between the two river deposits.

The body of water in which these deltas formed could have been retained only by an extensive ice-front on the north. The delta sands and the marginal features of the Vashon glacier during retreat both rest upon the till surface of the eastern glacier, and may be correlated with a strong degree of probability.

Six miles south of the front of this delta is a similar terrace at a higher level, which belongs to an earlier stage of the Vashon ice advance. It forms the plain north of Carbonado. On the road from South Prairie to Carbonado, 1.5 miles (2.4 kilometers) north of the latter town, a steep bank, 200 feet (60 meters) high, occurs. This bank is composed of brown sands, which are incoherent when dry and are generally of uniform character and interstratified with some layers of fine gravel. The summit of the terrace forms a nearly level plain, which is bounded by the deep canyon of Carbon river on the west, by its terrace front on the north, and by a deep ravine on the east. As in the previous case, the materials, the structure, and the form are all characteristic of a delta, which can, without question, be attributed to Carbon river. The elevation of this terraced front is 1,080 feet (329 meters) above sea.

A little more than 2 miles (3 kilometers) further south, among the foothills of mount Rainier, is a swampy level whose elevation is 1,600 feet (488 meters) above sea. Its area is about one square mile (2,589 square meters), and it lies against slopes carved in the Eocene coal measures. Along its eastern side, at the foot of the mountain slope, is the shallow channel of Flett creek. On the west is the canyon of Carbon river, 500 feet (150 meters) deep. The soil of this level is a sandy loam, and its northwestern front is a terraced slope about 350 feet (100 meters) high. The structure of the deposit is not exposed, and it is densely covered with the heaviest virgin forest of this luxuriantly forested region. It is allied in form and materials to the deltas that have already been described, and, if such be its character, must be attributed to the initial epoch of retreat from the maximum advance of the Vashon glacier. The elevation of the water in which this delta accumulated is about 1,000 feet (300 meters) above the level of the plateaus a few miles to the north, and the ice must have had a thickness of more than 1,000 feet to have formed the requisite dam.

The three high level deltas described have been mentioned in their sequence from the latest to the earliest. They all represent a condition when the northern ice-sheet ponded the waters accumulating along its face and held them against the hills to the south and east. The topography of the region was favorable to these local developments at high levels. No similar deltas are found toward the southwest, since in that direction there are no heights to confine the waters against the ice-front, and none have been observed further to the north, although it is quite probable that they exist in the favorable positions. The dense forest renders the discovery of isolated features a task of extreme difficulty.

*Kame terraces.**—When a glacier shrinks within its banks a stream develops on each side of it. Such a stream flows between the ice or lateral moraine on one side and the hill slope on the other. It may degrade or aggrade its channel and may bury ice-blocks in its bed. Flowing from the glacier into a lateral channel, the waters may farther on disappear beneath the ice. Their courses on the rock surface have no head nor any end at a local baselevel. When the ice has vanished their beds remain as terraces along the slope. Such streams may be seen on mount Rainier, adjacent to the stagnant ends of the glaciers, but they there have torrential falls.

An interesting result of corrasion by streams lateral to a former glacier is to be seen about 26 miles (42 kilometers) southeast of Seattle, in the upper valley of Issaquah creek. The valley is about one-quarter of a mile (.4 kilometer) wide and is divided along the middle by a line of low hills of drift material. Issaquah creek flows along the southern side. A row of swamps occupies an old channel on the northern side, and they drain across the valley by gulches through the central hills into the southern channel. The interpretation of these relations is that two streams developed in parallelism on the northern and southern sides of a shrinking glacier. As the ice disappeared they persisted and cut their

*This description of certain terraces had been written when my attention was called to Salisbury's definition of kame terraces in the Annual Report of the State Geologist of New Jersey for 1893, pp. 152 to 156. The definition applies to the terraces here described and the name is accordingly adopted, without change of statement.

channels below its bed. A central ridge remained, but it was cut across by branches of the southern stream, which captured the northern.

The following notes describe some of the benches whose characteristics indicate their origin as extramorainal or lateral stream terraces of this type, which Salisbury has called kame terraces.

Along the eastern side of the Duwamish valley east of Kent and thence northward the upper margin of the slope which rises to the plateau is terraced at elevations ranging from 385 to 440 feet (117 to 134 meters) above sea. The benches extend in sections along the slope for short distances of a mile or two. They are floored with sandy loam, which is sometimes gravelly. They are frequently higher along the margin next the valley and swampy toward the inner side. They are bounded on the east by a more or less abrupt slope of gravelly till 30 to 50 feet (9 to 12 meters) high. They represent short courses of streams, which flowed beside the Vashon glacier as it shrank from its expansion on the plateaus into the banks of the Duwamish valley. They therefore antedated the condition of ponded waters in the valley when the sandy deltas formed at lower levels.

The vicinity of Carbonado, where occur the high level deltas already described, presents other terraces attributable to Carbon river, acting in immediate proximity to the Vashon ice-front. These terraces extend from Carbonado northeastward and eastward around the lobe of drift deposits to and beyond Wilkeson. Not only Carbon river but also Gale creek and South Prairie creek modelled them in conjunction with the ice. At Carbonado the surface is cleared of forest and details are laid bare. A terrace whose upper surface is a wide flat, now at an altitude of 1,175 feet (358 meters) above sea, faces westward with a steep bank 25 feet (7 meters) high. It is composed of sand and coarse gravel, with boulders up to 2 feet (.6 meter) in diameter of rocks characteristic of the Vashon till. The materials are here heterogeneously mingled, there interstratified, and elsewhere the coarse gravel is washed clean. Precisely similar accumulations of gravel and sand characterize the upper valley of Carbon river, proceeding from the present glacier. The materials forming the upper terrace at Carbonado were in part at least carried forward in the furthest advance of the Vashon glacier and subsequently swept back by the river in an early stage of the retreat. The westward face of this terrace is steep at Carbonado, and is probably a cut bank along whose foot the river flowed northward. The ice was close by on the west and north.

At the foot of the upper terrace face is a wide flat of sandy alluvium under a thin veneer of pebbles and boulders. The elevation of this level at the depot at Carbonado is 1,150 feet (350 meters). It is therefore 70 feet (19 meters) above the margin of the delta terrace already defined as bounded by the contour of 1,080 feet (329 meters). It is separated from that delta by a slightly elevated margin characterized by kettles and coarse gravel, which represents a temporary stage of morainal accumulation. This morainal zone widens toward the north and east. Kettleholes 40 feet (12 meters) deep and 300 feet (91 meters) across are numerous and frequently tangent to each other They represent ice-blocks, which were buried by the river deposits as the stream flowed past the ice-front. Beyond the zone of kettles a deep gash in the terrace front leads down to the valley of Gale creek, debouching near Wilkeson at an elevation of 820 feet (250 meters). The gash marks a temporary water course.

The several deltas and stream terraces between the elevations of 1,600 and 1,080 feet (488 and 329 meters) in the vicinity of Carbonado and Wilkeson record the fluctuations of the furthest advance of the Vashon ice-sheet southeastward. They probably form a continuous sequence in which the highest is the oldest; but it is barely possible that the lowest belongs to the series of stratified deposits formed before the Vashon ice advanced. The fact that it is not covered by the characteristic till of the Vashon episode indicates, however, that it is later and was developed when Carbon river had been diverted from its northeastward to its northwestward course. The gash in the terrace front leading down to Wilkeson would seem to be of even slightly later date. If so, it was cut by a short-lived stream. The relations of ice-masses and rivers in the district between Carbonado and Buckley will yield an interesting result to detailed investigation.

The several courses of Cedar river, so far as they have been traced within the Tacoma quadrangle, record interesting relations between the Vashon glacier tongues and the Cascade glacier. From a point which is 5 miles (8 kilometers) north of Black diamond, Cedar river has at different times flowed south, southwest, north, and northwest, the last being its present course. The positions of the river were determined initially as the glaciers receding from confluence left between them a course open toward the southwest, and later as the further recession of the Vashon ice-mass uncovered lower outlets to the northwest.

The channels leading southward and southeastward are swamps, known as the Wilderness. Their elevation is about 450 feet (137 meters) above sea, whereas that of Cedar river at the point where it now bends northward from its older course, is 350 feet (107 meters). East of the Wilderness and lying 50 to 150 feet (13 to 38 meters) above it on strongly marked terraces are lakes. They are in the moraine of the Cascade glacier, whose extent at this stage is also indicated by till of local character derived from

Eocene sandstones east of Black diamond. Northwest of the Wilderness are high terraces, plains of well washed gravel, and a marginal zone of the Vashon glacier, including a number of lakes.

The northward trending channels differed from the present course only beyond the point were the river now turns from northwest to west by north. The stream formerly continued northwestward. Lakes, terraces, and plains of washed gravel pitted with numerous kettleholes show that it flowed over surfaces which are 350 feet (107 meters) above its present level, and that the ice-barrier was near at hand.

In this connection it is desirable to record the observations made on a dump of coarse gravel which occurs immediately east of Renton, where Cedar valley opens into Duwamish valley. From the point of the main plateau mass a sharp crested ridge projects 800 feet (240 meters) northward. At its junction with the slope of the plateau it is 200 feet (60 meters) high above the bottom lands of Cedar river; where the river cuts a section across its northern end it is 135 feet (41 meters) high. The section exposes stratified gravel which dips 15 degrees to the west. The pebbles are .5 to 3 inches (1 to 8 centimeters) in diameter, with occasional larger ones 6 to 8 inches (15 to 20 centimeters) through. An angular stone 12 inches (30 centimeters) on a side was seen. The eastern slope of this ridge is very steep, and, with the plateau on the south, partly encloses a rectangular corner in the flood plain of Cedar river. The ridge appears to be a gravel dump from the face of a glacier which occupied Cedar valley. The evidence of the ice in the valley indicates that the hollow antedated the present river.

Washed gravel plains.*—In the interiors of the plateaus are extensive plains, which frequently lie at lower altitudes than the marginal zones. The plains are strongly characterized by sterility. Scattered groups of small firs and stunted oaks standing in the expanse of scanty grass form a surprising contrast to the dense forest which prevails adjacently. The surface of any section of the plain is level, but successive surfaces rise by terrace steps toward the outer margins. The steps are from 3 feet (1 meter) to 25 feet (8 meters) high and are strictly horizontal along their margins. The evenness of the surfaces is locally broken by kettleholes, or even by obscure ridges. The material of the plains is prevailingly coarse gravel, sometimes washed clean, elsewhere mingled with coarse sand, usually stratified or cross-stratified. On the surface is a veneer of silt, which is filtered down among the loose pebbles beneath and forms a thin soil.

*The term washed is here used in its usual English sense to modify gravel which has been swept to its present position by swift streams and washed clean of all clayey matrix.

The Steilacoom plains, which extend for many miles south and southwest from Tacoma, constitute the type of this formation. It was studied most carefully in 1896 by my associate, Mr Smith, and agreeing, I adopt the following views from his manuscript report: The deposits of the Steilacoom formation are of glacial origin and present a peculiar type of washed plains. They differ from the ordinary type of outwash plain in their wide extent, in the widespread distribution of coarse material, in the absence of gradation from coarse to fine material in going from the morainic zones outward, and in the marked horizontal terraces. The superposition of horizontal terraces on uneven surfaces of morainic kettle-holes and ridges in such manner that the latter are more or less obscured indicates a sequence of conditions. The morainic features belong to an episode when the ice-front was for a brief period maintained along a given zone, whereas the terrace features are deltas formed in waters lying in front of the ice-face. The Steilacoom plains therefore represent an area from which the ice retreated, and which was submerged during the episode of retreat. The deltas might have been formed in shallowing or deepening waters. If the former had been the case the upper deltas should be more or less dissected and the lower should be well defined. The reverse is true. The lower deltas are somewhat masked by later deposits, whereas the upper deltas are sharp and complete. It therefore appears that during the development of the peculiar terraced surface the ponded waters were deepening, a result likely to occur during the retreat of the glacier where the topographic features afforded basins.

Thus the Steilacoom plain is a zone of glacial retreat, the glacial deposits proper being of low relief and for the most part covered or masked by gravel deposits mostly of delta character. This hypothesis seems best to account for the great extent of the plains, the isolated kame-like areas, the mound and basin surfaces, the different terraces, the gravels which compose the subsoil, and the silt which veneers the gravel surface. Had the lake been a more permanent feature at any level a gradation in grain of the deposits might be found, and at some distance from the ice the silt deposit should be thick enough to furnish a good soil.

The areas in which these plains are best developed are the Steilacoom plains already referred to and a district from 6 to 8 miles (10 to 15 kilometers) east of Kent. Plains of similar character, but less conspicuously sterile, occur 3 miles (5 kilometers) north of Des Moines, and also in the wider southern portion of Des Moines island. In each case the topographic type marks an area from which the confluent ice receded from the maximum expansion of the Vashon epoch. The wide Steilacoom plains were overflowed by the southern lobe. The area east of Kent was intermediate between the Vashon ice-tongue, which overflowed from the

Duwamish valley, and the Cascade glacier from the east. It was traversed by streams between the glaciers, and terraces of erosion are developed on it. The limited areas in the interior of Des Moines island developed between the two tongues of the Vashon glacier, one of which shrank back into the Duwamish valley and the other into Admiralty inlet. In each case the peculiar type of delta plain is bounded by a zone of level plains which are not terraced and which mark the unsubmerged outwash plain beyond of a morainic zone. The conditions of extreme expansion and of initial retreat appear to have been followed by an epoch during which the glacier stayed for a considerable interval at a stage which overflowed the hollows and produced marginal accumulations upon the edges of the plateaus.

Vashon drift, marginal features.—The components of the Vashon drift are round pebbles, sand, and loam. Compact clay is not a common phase of it. Angular and striated stones are in many places rare. The constituents are confusedly mingled over wide areas, but frequently they are sorted and even stratified. The roundness of nearly all pebbles and boulders suggests prolonged transportation in rivers. The structureless distribution with local bedding indicates deposition from ice with aid of glacial streams. The marginal zones are composed of essentially the same materials as the ground moraine, with the addition of large erratics, which are not numerous. The pebbles are throughout prevailingly of granite, of a variety which forms the mass of the northern Cascades. The granite boulders are sometimes exfoliated and crumble, but the feldspars are not materially decomposed. This fact serves to distinguish the Vashon gravels from others, which will be called the Orting gravels, in which the granite boulders can frequently be cut like stiff clay.

The topographic configuration of the Vashon drift varies from smooth plains to a relief which exceeds a hundred feet (30 meters). In the following description of their distribution the marginal zones are distinguished from the till by characteristic topography rather than by differences of material or of internal structure. The distinction which was made in the course of field work is sustained in mapping by the relative arrangement of the different types. Areas of undulating surfaces of gravelly loam, which are classified as till, are bordered by zones which are marked by ridged and hummocky relief. The gravel ridges and the irregular hills and kettleholes decrease in magnitude to the farther limit of the outer zone, and there give place to smooth plains which belong to the class of outwash plains or to terraced plains of washed gravel of the Steilacoom type. These relations are characteristic of formations marginal to the ice. They define the direction in which it faced, and thus aid in determining the positions of the ice-tongues at various stages. Definitely marked terminal moraines across the front of the glacier at any stage have not been observed.

The northwestern portion of the plateau which lies between Cedar river and Green river is marked by a zone of Vashon drift which presents a marginal aspect. On the southeast the zone is bounded by the washed plains of the former course of Cedar river through the Wilderness. Beyond these plains eastward is the local drift of the Cascade glacier. The Vashon ice and the Cascade ice met along the Wilderness. In many places a steep slope rising along their northwestern side defines the limit between the washed gravels and the gravelly loams of the Vashon marginal zone. The latter is about 3 miles (5 kilometers) wide from southeast to northwest. It includes many lakes, of which Swan lake is the largest. The relief within the zone is 100 feet (30 meters) or more in height, not including the deeper pre-Vashon hollow occupied by Big Soos creek. The forms are, however, broad and lack definition. Summits, slopes, and hollows merge obscurely. Nothing is clearly cut in profile. Broad ridges of coarse material merge longitudinally into mammillated surfaces which pass into smoother plains of typical till. Between the ridges hollows of irregular depths and contours are floored with sands or loam, and now contain muck-swamps. The ridges trend from west of north to east of south in a general way parallel to Big Soos hollow. This trend is at right angles to that which would be assumed by a terminal moraine, such as might have formed had the glacier ended with a free front.

The marginal zone of the Vashon ice is interrupted between Green and White rivers. Drift is probably buried beneath alluvium in their valleys. The narrow plateau between them is washed as are the plains along the Wilderness, presumably by the same streams, but on the plateau between White and Stuck rivers the Vashon drift exhibits strongly marked marginal characteristics. Among bold ridges which trend southeastward lies lake Tapps, typically fingered. The southeastern margin of the Vashon drift here runs out upon the plains of Osceola till, on which extend the swamps drained by Fennel creek. Southward the zone extends along the western edge of the plateau in a belt about 3 miles (5 kilometers) wide, over the hill above Orting, whose summit is 900 feet (274 meters) above sealevel, and thence spreads southeastward to Carbonado and Wilkeson. In this southeastern district the Vashon ice impinged against glaciers from mount Rainier and its foothills. The arrangement of the spurs coming down to Wilkeson prevented the Rainier glaciers from flowing out directly against the Vashon ice, and thus it was left free to push farther in this direction than it could have extended except in the lee of high ridges.

From lake Tapps to Carbonado the relief of this marginal zone is not regular. Where Fennel creek flows southward its course is determined on the west by a ridge which is a lateral moraine of the ice-tongue that filled the Puyallup valley. Over Orting hill the drift is irregularly heaped, though broadly ridged on trends which descend steeply northwest. Between Carbon river and South Prairie creek the relief presents the character of transverse ridges, which may be called kame moraines of various stages of retreat. They are associated with pitted plains and delta formations and alternate with stream channels.

West of Puyallup valley to Tacoma the Vashon drift is characteristically heaped and ridged northeast of Steilacoom plains. West of Orting a notch is cut in the plateau scarp where it turns from south to southeast. The Vashon drift extends south to the notch and forms a ridge above the 500-foot contour thence southwest for 4 miles (6 kilometers). A till composed of materials from mount Rainier extends northward to the 600-foot contour. A washed gravel plain lies in a triangular space between the two kinds of drift. From the southern limit thus defined, the Vashon drift extends northward in a zone .5 mile to 1.5 miles (.8 to 2 kilometers) wide. On the east, next to the plateau scarp, its relief is irregular; kettleholes and mounds confusedly mark an elevated margin. South by west from Puyallup a depression, with strongly terraced slopes, extends through the marginal zone to the plains. From this hollow west beyond Tacoma the relief is characterized by strong gravel ridges, which trend from north to south. They are very conspicuous on the highland southwest of Tacoma. They are of the same type as those which have been described as occurring northwest of the Wilderness and about lake Tapps, and, like them, they run in a course which is transverse, not parallel, to the limits of the Vashon drift.

In each of the localities in which the marginal zones with transverse ridges are strongly developed the Vashon drift is spread upon high ground, with relatively lower surfaces beyond in the direction of ice movement. Subglacial streams flowed longitudinally to the ice in the direction of the transverse ridges. It is inferred that the effect of running waters in modeling the under surface of the ice and in transporting drift beneath the ice determined the marginal drift type.

Following Chamberlin's genetic classification of Pleistocene glacial formations,* the marginal forms just described fall technically under two

* T. C. Chamberlin: "Proposed genetic classification of Pleistocene glacial formations." Journal of Geology, vol. ii, No. 5, 1894.

types. The ridges of coarse, more or less stratified gravel, trending in a direction transverse to the ice-limit, conditioned by the slope of the land, and formed beneath the ice, correspond to osars.* The areas of billowy relief which are associated with the osars or which occur as tracts between groups of osars are of the class of submarginal or lodge moraines.†

Vashon drift areas, interior aspects.—It is probable that the Vashon drift presents varied aspects in different districts. In the marginal zones the absence of angular or striated stones is striking. Such stones are more numerous on Vashon island, according to the observations of Mr Smith. They also occur, though in limited numbers, on Des Moines island. Where present they indicate that the gravels were not so vigorously rolled by streams, but have been carried in the lower strata of the ice. Farther northward, at greater distance from the margin, ice may have been the principal carrier, and the till may have a correspondingly clayey and angular character.

The topographic aspect of an area of Vashon till, where it has been spread by ice, is that of a gently undulating plain diversified by occasional kettleholes. The ground is a gravelly loam, but within the district so far surveyed no extensive area of unmodified till has been observed. Bodies of sorted pebbles or sands and interstratified lenses of sands in heterogeneous gravels suggest the concurrent action of water with the ice in subglacial channels.

In the northern part of Des Moines island, 6 miles (9 kilometers) west of Renton, is a group of round hills and short ridges worthy of note. The locality is known as Sunnydale, and numerous homes are established there on account of the fertile soil. A central hill of oval plan and something over 100 feet (30 meters) high is surrounded by mounds and short ridges. The general arrangement trends from north to south, covering an oval area of about one square mile (259 hectares). On the north is an undulating plain of Vashon till. Southward a small stream, which rises in swampy hollows between the hills, pursues a relatively wide depression. The material composing the hills is prevailingly gravel and sand under a cover of sandy loam with comparatively few pebbles. Bodies of sand occur. On the crest of some of the ridges there is clean gravel. Large boulders are numerous on the surface. In the southern part of the area specially distinct ridges and oval hills consist of gravel and sand interstratified, cross-bedded, and laid with plunge structure. The oval hills and short ridges which make up this group appear to have been formed under the ice by the action of subglacial streams,

* Op. cit., p. 529.
† Op. cit., pp. 524, 525.

but they may have been accumulations along the margin of the ice, and thus belong to the class called kames.

Geology of the Pleistocene Epochs

GENERAL STATEMENT

The preceding pages present the existing topographic aspects of the Puget Sound basin, and particularly those of the Tacoma quadrangle. The topography is so directly a result of geologic conditions that it involves a statement of the nature of the latest episode of glaciation; but the further description of glacial and interglacial formations belongs to the subject of geology. Therefore the facts and inferences of the Vashon episode are here summarized and followed by a description of the underlying Pleistocene formations. The various deposits occur separately in different sections of the plateau slopes, and correlation from one exposure to another is not always sure. The principal sections are given in tabular form at the close of this chapter. The first (Section A) may be regarded as typical, as it includes all of the members found elsewhere.

THE VASHON GLACIAL EPOCH

Definition of terms.—The Vashon episode has already been defined as covering that interval of Pleistocene time in which the glaciers most recently spread into the Puget Sound basin and there became a confluent ice-mass. The name Vashon, from Vashon island, is given specifically to the ice-tongue which then pushed southward from the highlands of the San Juan archipelago; but the Vashon episode also covers the expansion of the contemporaneous glaciers from the Cascades and mount Rainier, of which one, the Osceola tongue, is known by its distinctive till.

Summary of the Vashon history.—In consequence of the advance of the Vashon glacier, there was carried from the north a mass of gravel, sand, and loam, which was spread over wide areas of the Puget Sound basin as the latest drift sheet. The glacier extended far into the southeastern arms of the sound, the extreme limit as yet recognized being a short distance south of Carbonado and about 1,600 feet (488 meters) above the present sealevel. The margin of the gravelly Vashon till is not marked by terminal moraines, but is characterized by osars. The deposit—in large part, at least—is of subglacial origin, modified by streams. Portions of it may be englacial or superglacial. Its limits are related to the topography of the region over which the ice stood. They do not necessarily correspond to an ice-front or the face of the glacier, and probably along certain sections the Vashon ice did not present a face. Along such sections—as, for example, the line of the Wilderness swamps—it was opposed by and became confluent with glaciers descending westward or northward.

The maximum thickness of the confluent ice as yet determined was 1,600 feet (488 meters) above the present sealevel, or 1,000 to 1,200 feet (300 to 400 meters) above the plateaus. As the ice filled the Duwamish valley, and without doubt also the hollows of Admiralty inlet and other sounds, its thickness along their courses must have been 1,600 feet (488 meters) plus the depth of water, at least. Over the greatest depth of Admiralty inlet the ice was, therefore, not less than 2,500 feet (800 meters) thick, and if allowances be made for southward slope of its upper surface, it was probably more than 3,000 feet (900 meters) thick.

That the ice occupied the Duwamish valley is shown by the occurrence of drift and lateral moraines along the slopes of the valley. From this fact follows the important inference that the hollow of the Duwamish valley is older than the last glacial advance. It is not a channel of post-glacial erosion. The relations of the homologous hollows of Admiralty and other inlets to the Duwamish valley is such that the inference necessarily extends to them also. Hence we may conclude that before the Vashon epoch the major features of Puget Sound physiography were similar to what they are now. The Vashon ice invasion modified but did not obliterate the major antecedent topographic features, and they still persist.

The effect of the Vashon invasion on the topographic configuration of the region was constructive. The Vashon till is spread as a sheet, which is a general addition to the masses of the plateaus. It is of very unequal thickness. Observations of its extent on steep slopes vary from 25 to 200 feet (8 to 60 meters) below the summits, but they are of little value as determinations of thickness, since they are liable to errors due to over-placement, landslides, erosion, and inequalities of the underlying surface. Wells which might yield more satisfactory results have not done so, as the base of the Vashon drift is not easily distinguished. Where the drift is heaped in osars and lodge moraines the thickness materially exceed the average. Taking these excesses into account, it is reasonable to assume that the volume is equal to that of a uniform sheet 65 feet (20 meters) thick extended over the areas of the plateaus. The hollows are not included, as there is no equivalent basis for an estimate of the amount of till beneath the alluvium and water.

As the thickness of the Vashon drift is abruptly variable, the distribution of its greater additions to the antecedent relief may be observed. They are found to be marginal to the plateaus and to be highest near the outer rims. When the ice filled all the hollows and overflowed over the plateaus, subglacial streams could escape with current sufficient to carry gravel only over the plateau surfaces. As the ice melted back the interiors of the plateaus were first laid bare. They were scoured by the escaping waters, while yet osars and lodge moraines formed about the margins. When the ice sank into the hollows the internal drainage of the plateau areas persisted, finding such outlets as are indicated by Fennel creek and Big Soos creek. The resultant effect on the topography of the region was to build up the plateau margins and to establish an inward flowing system of drainage in each plateau area.

The effect of Vashon glaciation in narrowing and filling the major hollows is obscured beneath the more recent sediments and the water bodies of the sounds. Invading the region, the ice first occupied the hollows. Melting away, it lingered longer in them than on the plateaus. As the lowest part of the glacier, the ice in the hollows was probably very densely charged with gravel. The depth of the hollows at the present time represents the thickness of ice, less the amount of later sediment, beneath which lies the gravel which the ice contained.

The formations which in addition to the Vashon drift constitute the record of the Vashon epoch may now be described.

Osceola till.—The name Osceola is here given to a sheet of till which covers the plateau between Green and White rivers and extends southwest beyond White river about the head of Fennel creek. It is covered by the osars around lake Tapps and by the delta sands on the south.

The Osceola till consists of fine silt with numerous angular stones. The silt is a glacial meal such as White river carries at the present time. The stones are prevailingly, if not almost exclusively, fragments of Tertiary or later volcanic rocks. They are coated with a limy deposit and with the clinging silt. The till forms a hardpan upon which the growth is that of swamps. Peat bogs are numerous over its area.

This till was spread from the east directly by a glacier descending from the Cascades. It is easily distinguished from the Vashon till by its compact silty constitution and numerous stones of volcanic rocks. It also contains blocks of Eocene sandstone and shale. Water, which played so important a part in distributing the Vashon till, was a subordinate agent in the formation of the Osceola till.

The Vashon osars about lake Tapps appear to rest on the Osceola till, and consequently to be younger. The two formations, nevertheless, probably belong to one epoch of glaciation. The source of the Vashon ice was remote, that of the Osceola ice was comparatively near. The Vashon glacier advanced first along the deep hollow of Duwamish valley, the Osceola glacier descended from the foothills on to the plateau. From these relations it follows that the Osceola till may have been spread while the Vashon glacier was still confined in the hollow or even distant, though advancing. After the glaciers became confluent and rose to a thickness of 2,000 feet (600 meters) above sealevel, subglacial channels developed beneath their combined mass, and in these channels the Vashon osars formed.

Osceola clays.—Blue-gray clays of the aspect and compact character of the Osceola till, but unlike it in being stratified, occur between 650 and 700 feet (200 and 213 meters) above sea, in the bluffs which form the north bank of Carbon river, 2 to 3 miles (3 to 5 kilometers) below Carbonado. The deposit is very evenly stratified in horizontal layers, which differ slightly in proportions of clay and very fine sand and weather out as ribs on the vertical face. The formation oxidizes to a deep brown color and assumes the aspect of a carbonaceous clay at a distance, but it contains no vegetal remains. It is also free from pebbles.

This clay was deposited in quiet water. Upon its even upper surface the Vashon ice spread subglacial gravels. The clay apparently immediately antedated the expansion of the ice-sheet over this area. It is of local distribution only, and the waters in which it was deposited were not extensive. They could have been ponded only by an ice-front on the north. The character of the materials identifies it with the Osceola till, which was spread by the Cascade glacier at higher levels than this to the northeastward and subsequently at lower levels to the northward of this occurrence. Thus this clay is correlated with that stage of advance of the Vashon and Cascade ice-sheets when they enclosed a water body between their fronts and the hills to the south and southeast.

Along the plateau face on the east side of Duwamish valley beds of blue stratified clay underlie the Vashon drift. The highest exposure was noted 3.5 miles (5 kilometers) north of Kent, at an elevation of 310 feet (94 meters) above sea; the lowest was seen 5 miles (8 kilometers) south of Auburn, 105 feet (32 meters) lower, or 205 feet (62 meters) above sea. It is not to be inferred that there is a uniform sheet of glacial clay 100 feet (30 meters) thick extending over a wide area. In the advance of the Vashon glacier waters were ponded at various levels, and the separate ponds received similar sediments successively. Of these the southern occurrence on Carbon river is probably the latest. Sand and gravel deposits formed contemporaneously with these clays and may occur at the same horizons.

Similar clays occur at much lower levels and are correlated with the preceding or Admiralty epoch of glaciation.

Douty gravels.—Beneath the Osceola clays in the section exposed in the northern bank of Carbon river is a deposit of gravel between 600 and 655 feet above sea. This may be designated the Douty gravels, the station of Douty in the canyon near Carbonado being the nearest point having a specific name and at the level of this bed. The material is thoroughly rounded. Sand, small pebbles, and larger pebbles up to 6 inches (15 centimeters) in diameter are intimately associated, with irregular stratification and occasional cross-bedding The formation is such as is now being formed by Carbon river, which is overloaded with coarse and fine detritus from the glaciers of mount Rainier. Five to 15 feet (2 to 5 meters) above the base of the Douty gravels in the section observed rocks of subangular form up to 4 feet (1⅓ meters) in diameter were observed. In association with the coarse, stratified gravel they suggest transportation on ice-cakes.

The Douty gravels thus indicate a river, comparable in transporting power with Carbon river, flowing from a glacier and sweeping down loaded ice-cakes. The episode immediately antedated the Osceola till and may safely be correlated with an early part of the Vashon epoch. The formation is local and should not be identified in other drainage areas where the dates of similar formations, although of the same epoch, may nevertheless be materially earlier or later.

PUYALLUP INTERGLACIAL EPOCH

History of the Admiralty ice-sheet.—The term interglacial is here applied to an epoch of milder climate than that which permitted the accumulation of extensive glaciers in the Sound basin. The degree of mildness implied is relative only. An ice-sheet which will hereafter be described as the Admiralty ice-sheet had occupied the Sound basin. Its withdrawal was occasioned by the change to the milder climate of the interglacial epoch. A return of more severe climatic conditions caused the development of the Vashon glacier, which vanished with the gradual advent of the present mildness.

The record of the inter-Admiralty-Vashon, or Puyallup, epoch may exist in various forms, as eroded surfaces, as subaerial deposits including soil and swamp accumulations, and as lacustrine or marine formations. The duration of the epoch may be indicated directly by the magnitude of the effects of erosion or deposition, or indirectly by results of oxidation and decay of Admiralty formations as compared with the condition in these respects of Vashon drift.

We have as yet no knowledge of these various facts sufficient to permit us to draw a conclusion as to the character of the Puyallup epoch. It is possible that the Admiralty ice disappeared completely from the lowlands and even from the mountains; but as glaciers now linger in the Cascades, such total disappearance would indicate an interglacial climate warmer than the present, which is not probable. It is not unlikely that the condition of the Sound basin, as the Admiralty ice stagnated and melted, came to resemble that of southern Alaska about the margin of the Malaspina glacier, which Russell has so well described.*

Such evidence of a milder climate as I have gathered is apparently related to deposits which accumulated during the retreat of the Admiralty ice and might be correlated under the head of the Admiralty epoch, but the stagnant ice locally lingered long after the condition of general glaciation had ceased to be, and no sharp line can be drawn between the glacial and interglacial epochs. So far as is now known, the latter epoch is not represented by deposits formed under climatic conditions indicative of an entire absence of glaciers from the region. Therefore, in order to give the interglacial epoch definition, it is well to assign to it those formations which bear evidence of a milder climate, in spite of the fact that they also record persistence of the slowly melting ice. These are well represented in the Puyallup valley, and the name is therefore given to the interglacial epoch. The formations correlated with this epoch are the "Puyallup sands" and "Orting gravels" and the structure which will be described as the "Tacoma delta." By inference, though not by direct tracing of formations, extensive lignite beds also belong in this group.

Pursuing the method of reading the geologic record from the more recent to the earlier episodes, it is necessary to describe formations occasioned by retreat of the Admiralty ice before having given the facts which demonstrate the former existence of that glacier; but the description of the Admiralty till, the earliest glacial deposit as yet recognized above sea-level in the Sound basin, will leave no doubt on the minds of those who may refer to it. I therefore take up the latest of the formations of the Admiralty epoch.

Puyallup sands.—In a number of sections observed about the Puyallup valley and in one on Green river the earliest formation attributable to the Vashon epoch rests on an eroded surface of stratified sand. Where the fact of erosion is not apparent, the contact is nevertheless marked by the superposition of very coarse gravel and large boulders on the deposit of fine sand, evenly stratified. The principal occurrences observed may be enumerated as follows:

In bluffs on Carbon river the coarse Douty gravels lie upon the edges of sand beds, which are cross-stratified at a dip of 20 degrees to the southwest. The upper surface of the sands varies 1 to 5 feet (.3 to 1.5 meters) from a plane in consequence of erosion. The bed of sand is about 40 feet (12 meters) in thickness. It is the delta of a stream which here extended as a steep bank southwestward into quiet water. The upper surface of the sands is 600 feet (182 meters) above sea.

* National Geographic Magazine, vol. 4, 1892, and U. S. Geological Survey, 13th Annual Report, 1892.

At Orting the east bank of the Puyallup valley is undercut by Carbon river, and the steep hillside is traversed by a road grade which exposes the strata up to 640 feet (195 meters) above sea. Above that point is coarse Vashon drift. From an elevation of 640 feet (195 meters) down to 410 feet (125 meters) the hill is composed of incoherent sands with occasional small pebbles; below 410 feet (125 meters) and down to 340 feet (104 meters) above sea the sands include lenses of fine incoherent gravel. The exposes are rendered doubtful by the looseness of the material, which slides, but there is no doubt that the hill is a body of delta sands capped by Vashon drift. Considered in relation to the older topographic masses to the east, this delta may be attributed to a former course of White river. The deposit may be divided by an unconformity, but I think it consistent with the occurrence of the Puyallup sands on Carbon river 4 miles (6 kilometers) east of Orting to associate the two bodies of sand as parts of one delta. If that be so, the whole mass near Orting is of the Puyallup sands. The mass lies higher than other occurrences. It thus indicates the highest level of the water into which the sands were discharged, and may be supposed to have presented a somewhat steep delta front to the west.

The west bank of the Puyallup valley 4 to 5 miles (6 to 8 kilometers) north of Orting presents a vertical face at several points. The cliff is maintained by a stratum of friable sandstone of exceedingly fine and uniform character. The bed is 40 feet (12 meters) thick above the talus slope which conceals the base. It extends from 200 to 240 feet (60 to 73 meters) above sea. The deposit is devoid of fine lamination and presents the massive appearance of an accumulation in a depth of water beyond the reach of currents. Variation of material from fine sand to shaly or clayey layers brings out an even horizontal bedding. Its color is gray and bluish. A layer of white clay 3 feet (1 meter) thick near the middle of the exposure contains minute bits of carbonaceous material. The sand is locally cemented by calcareous tufa, deposited probably from hot springs, as was the more extensive tufa bank a mile eastward on the eastern side of the valley.

This occurrence of the Puyallup sands on the west side of the valley may be considered typical, and the deposits occurring at other localities and described under the same name are correlated with it with more or less certainty.

Orting gravels.—Throughout the Puyallup valley coarse gravel deposits underlie the Puyallup sands. In heterogeneous composition and varying structure they resemble the Vashon drift, particularly where the latter has been distributed by water. These gravels beneath the Puyallup sands are called the Orting gravels.

Their distinguishing characteristics are: Their position beneath the other formations; their coarse heterogeneous composition, including sands, numerous big pebbles, and boulders; their color, which is frequently orange brown, and the decomposition of granite pebbles, which, although not general, is of such repeated occurrence as to mark the age of the formation in contrast to the fresh Vashon drift.

In the section exposed in the north bank of Carbon river these gravels are conspicuous on account of their color. They form the lower part of the bluff between 500 and 560 feet (150 and 170 meters) above sea. They are interbedded with orange-colored sands and exhibit much variety of texture and bedding in adjacent sections.

At Orting they are well exposed on the east bank of Carbon river, where they present a very compact mass of heterogeneous materials. They are now to be seen from 200 to 340 feet (60 to 100 meters) above sea, between the river bank and the overlying Puyallup sands. Their characteristic color is less pronounced in this and other occurrences along the Puyallup valley. On the west side of the valley, 4 to 5 miles (6 to 8 kilometers) north of Orting, these gravels frequently form vertical or overhanging steeps.

Along the eastern side of the Puyallup-Duwamish valley there are exposures of stratified sands and gravels, two of which, one 4 miles (6 kilometers) and another 9 miles (14 kilometers) north of Orting, are described in the accompanying detailed sections. The former of these, lying between 100 and 170 feet (30 and 52 meters) above sea, exhibits an interesting structure. The distinctly stratified beds of gravel and sand dip from both ends of the exposure toward the center. They are traversed by numerous small normal faults, also inclined from either end toward the middle, which is thus additionally depressed. The structure is that which might probably be produced by slow wasting of a buried ice-mass, and as such it appears to indicate the presence of stagnant ice during the deposition of these particular beds. These strata are in part readily correlated with the Orting gravels, but their upper portion may correspond with the lower beds of the Puyallup sands.

Evidences of mild climate.—The deep orange color of the Orting gravels is due to the hydrated oxide of iron with which they are in part cemented. The ferruginous coating of sand grains and the stain on pebbles is so uniformly diffused in the mass that the accumulation of iron oxide appears to have been a condition closely connected with original deposition. It thus differs from the superficial rusty aspect of those blue clays which oxidize and turn brown on exposure to the weather. The blue clays are usually till spread beneath ice or sediments derived from till and deposited in icy waters. The iron which they contain was prevented from oxidizing by unfavorable conditions, of which cold was one. By contrast it may be inferred that the temperature was higher—that is to say, the climate was milder—when the Orting gravels were stained with oxide of iron.

Decomposition of iron minerals is promoted by decaying vegetation, and in many formations of various ages the occurrence of iron deposits is associated with peat or lignite. The presence of iron oxide in the Orting gravels thus suggests the development of vegetation in the region after the retreat of the Admiralty ice-sheet.

Lignite occurs so generally in formations belonging to the Puyallup epoch that the evidence of iron oxide in the gravels is of minor consequence. Its distribution in bluffs along Admiralty inlet has been observed by Russell; but before quoting his observations I wish to note an occurrence in Carbon River canyon, which can be definitely correlated with the Orting gravels. On the north side of the river, 1.25 miles below Carbonado, a short railroad cut exposes a section through a remnant of sandy clay which rests on Eocene strata. The remnant is preserved from erosion by a boulder, 8 feet in diameter, which is partly buried in gravel on top of the clays. The clays contain lignite. It occurs in bits arranged with the horizontal stratification and in larger pieces, one of which was a slab of wood 4 feet (1 meter) in length. The elevation of the lignite bed is 570 feet (174 meters) above sea, in the horizon of the Orting gravels.

At first sight this occurrence might be attributed to the modern river in whose channel lie the clay and boulder, but it is obvious that the torrent which could possibly roll the great stone would simultaneously wash away the clay and lignite. The even bedding of the deposit was the work of comparatively quiet water, and the boulder was dropped by ice into its present seat. The relations thus demonstrate the simultaneous presence of driftwood and ice. The suggestion that the lignite is of earlier origin, and was deposited as lignite rather than as wood, is apparently negatived by the character of the lignite. It is unlike the Eocene lignites and like those of the interglacial epoch.

The remnant of lignite bearing clays lies between the railroad and the river. On the farther side of the track is a bluff of Eocene shale. Thus the clays lie close to the foot of a cliff, which had developed before the Orting gravels were deposited, which was buried by the gravel and by subsequent formations, and which has been resurrected by the present river. The occurrence is therefore of importance in its bearing on the character of the topography during the Pleistocene period.

In a report from the field after making a reconnaissance of Admiralty inlet south of Everett, in August, 1896, Russell sums up his observations on the occurrence of lignite. Designating all the stratified formations between an upper till (probably the Vashon) and a lower till (possibly the Admiralty) as the "Medial sands and gravel," he writes:

"In the lower portion of the Medial sands and gravels, frequently resting on the lower till, there is a lignite deposit. The lignite occurs in beds frequently from 4 to 6 feet (1 to 2 meters) thick, interstratified with sands and clay, which are more or less thoroughly charged with organic matter. The thickest deposit of lignite observed occurs at Possession Head, where from 50 to 60 feet (15 to 18 meters) of lignite sand and clay are exposed. The lignite contains flattened stems 6 to 8 inches (15 to 20 centimeters) across, and occasionally impressions of leaves resembling those of the alder. When burned the lignite leaves a fine white ash resembling diatomaceous earth.

"The lignite deposit is widely spread. I have seen it at Port Townsend, Skagit Head, Possession Point, and Tacoma. It occurs also at Seattle, according to Professor Landes, and is reported to be present at Port Gamble."

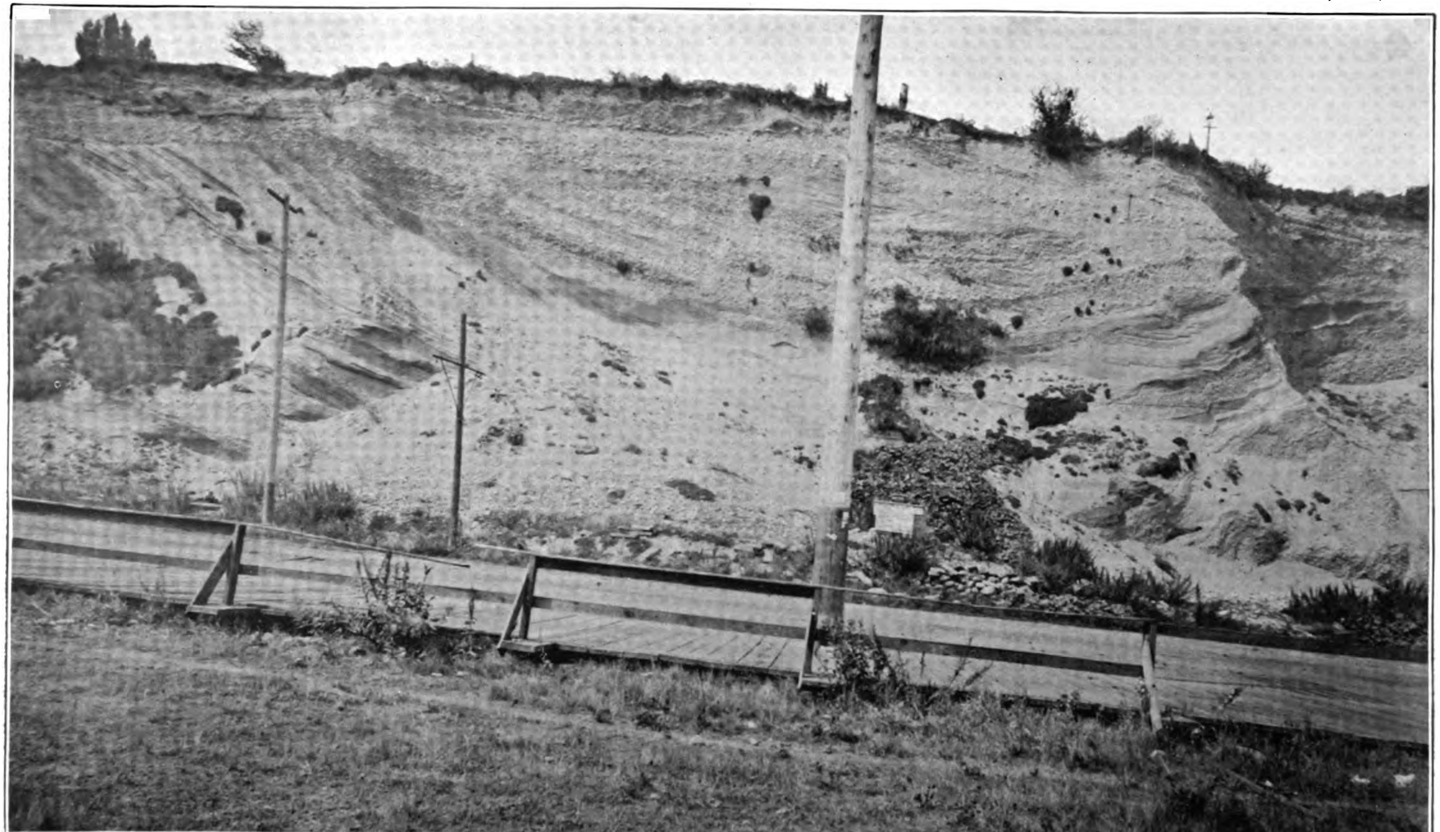
The climatic significance of these lignite beds will be ascertained only by careful study of their nature. The conditions of deposition, and especially the kinds of plants and trees which compose them, need to be determined; but in so far as the lignite is identified with the Orting gravels, its forest growth was contemporaneous with stagnant ice upon which they accumulated. The conditions may then have been similar to those of the Alaskan coast and the Malaspina glacier, of which Russell has written: *

"The outer and consequently older portions of the fringing moraines are covered with vegetation, which in places, particularly near the outer margin of the belt, has all the characteristics of old forests. It consists principally of spruce, cottonwood trees, alder, and a great variety of small shrubs and bushes, together with rank ferns. The vegetation grows on the moraine, which rests on the ice. In many places the ice beneath the dense forest is not less than a thousand feet thick.

"The vegetation is confined principally to the border of the Seward lobe of the glacier. Near the Yahtse the belt is 5 miles broad, but decreases toward the east, and is absent, as previously noted, at the Sitkagi bluffs, where the glacier is being eaten away by the sea. It is only on the stagnant borders of the ice-sheet that forests occur. Both glacial lakelets and forests on the moraine are absent where the ice has motion. The forest-covered portion of Malaspina glacier is by estimate between 20 and 25 square miles (5,172 and 6,465 hectares) in area.

"The lower ends of the Lucia and Atrevida glaciers are also forest-covered, and similar conditions exist on some of the glaciers flowing north from the St. Elias mountains, as was observed by Dr C. W. Hayes † during his recent exploration in that region."

* Second Expedition to Mt. St. Elias, 13th Annual Report U. S. Geological Survey, p. 76.
† National Geographic Magazine, vol. 4, 1892, p. 152.



SECTION EXPOSED ON PACIFIC AVENUE, TACOMA

Showing the Vashon till overlying the older portion of the Tacoma delta

Tacoma delta.—Among the formations which I may provisionally place in the Puyallup group is, in part at least, a voluminous delta underlying the city of Tacoma. A portion of the structure belongs to the Vashon epoch, another part underlies the Vashon till and probably was formed during the Puyallup epoch. The whole is dependent upon broad topographic relations for its development.

South of Tacoma expand the Steilacoom plains. North of Tacoma is the deep hollow of Admiralty inlet. The general elevation of the plains is 350 to 400 feet (100 to 120 meters) above sea; but about their eastern, northern, and northwestern margins they are bounded by higher zones, rising to 500 feet (150 meters) or more above sea. Their general slope near Tacoma is northward. Thus their topographic configuration is that of a shallow basin. The plains are diversified by numerous low delta terraces, which prove that the basin once held water. At the northern point is an outlet, a depression marked by abrupt terraces, which turns eastward and opens upon a deep gulch that leads down to sealevel. The railroad follows the outlet and the gulch. Sections of the gravels exposed in the gulch exhibit the cross-stratification characteristic of deposits from swift streams, and the steep bedding of the deposit confirms the inference, from its general relations, that it is the delta of a river which flowed from the Steilacoom lake. All of this belongs to the latest (the Vashon) epoch.

The broad slope on which the city is chiefly built lies north of this gulch and is covered with Vashon till. Beneath the till is a remarkable mass of sands and gravels, exhibiting the structure shown in plate 9. The photograph was taken on Pacific avenue, a short distance north of the city hall. Near the top of the section is a line of coarse pebbles which mark the base of the Vashon till. Beneath this unconformity is a lenticular body of gravel steeply bedded and spread over the edges of the underlying layers. The lower and greater part of the section is of sandy clays, which exhibit the plunge structure peculiar to deposits from swift currents, overloaded with sediment, entering a still-water body. Structure of this type may be traced along the bluff for a half a mile.

The delta structure is complicated by dips in a direction opposed to the general inclination, which result in synclinal depressions, one of which is shown in plate 9. The subsidence is exaggerated by faulting, with inclination of the fault plains toward the downthrow. Small faults of this type give a zigzag section to some of the beds seen at the right of plate 9. These peculiarities, taken in connection with the very steep dips of the strata, appear to indicate that the mass was deposited on or included in ice, which, melting, allowed the layers to subside locally.

The Tacoma delta is a complex structure, which should be studied in great detail and with reference to all the formations related to it. It may then yield important data bearing on phases of the interglacial history.

ADMIRALTY GLACIAL EPOCH

General statement.—Beneath the Puyallup stratified formations are unstratified deposits characteristic of glacial conditions. They record a glacial advance which was probably quite as extensive as that of the Vashon epoch, but which can never be known in the same complete detail, as the till and its associated beds are deeply buried. The principal exposures of these glacial formations are to be seen in the bluffs along the shores of Admiralty inlet. The name Admiralty is therefore given to the epoch.

Admiralty till and clays.—This formation was first recognized by Russell during his reconnaissance, although referred to, from Everett to Tacoma. In his brief report he describes it as—

"A thick deposit of stiff, blue clay, usually in evenly stratified beds, but occasionally changing gradually to a well characterized till filled with subangular stone and gravel, together with occasional boulders, some of which are glaciated. This deposit is frequently exposed about the immediate shores of the Sound, and forms precipices from a few feet to fully one hundred feet high.

"The upper surface of the lower till is irregular in many places and sometimes deeply eroded. For this reason it is not seen at some localities where it might be expected to occur, its place being taken by stratified sands and gravels."

Within the area which I have personally examined the Admiralty formations are rarely exposed. The observations may be noted as follows:

At Tacoma stiff blue clay, minutely bedded, forms a vertical bluff above the steamer wharf. As the clay turns water and is overlain by the porous sands of the Tacoma delta, its upper surface is marked by a line of springs. In the southeastern part of the city, near the freight depot and 30 to 40 feet (10 to 12 meters) above sea, are sections of sandy clay containing large boulders. The deposit is unstratified. The absence of structure and the association of coarse and fine material identify it as a true till or ice-laid formation. Its characteristics are shown in plate 10.

Along the western shore of Des Moines island the Admiralty till occurs occasionally near sealevel in places rising in bluffs 10 to 40 feet (3 to 12 meters) high, and again passing out of sight below tide. It is a stiff sandy clay with numerous rounded pebbles and angular stones.

On the eastern side of the Duwamish valley near Kent a till, which is correlated as the Admiralty, occurs below the Vashon till separated by finely stratified sands. In a gulch 3 miles (5 kilometers) southeast of Kent this lower till occurs as a nearly vertical scarp between the elevations 120 and 175 feet (37 to 53 meters) above sea. It is a bluish gray,

BLUFF OF ADMIRALTY TILL, TACOMA

This exposure of till, 35 feet above tide, is shown on the left of the view. The boulders in the foreground are derived from it

sandy clay of such compactness as to occasion a waterfall. It includes many rounded, angular stones, most of them of small size. The Vashon till at this point, 200 to 300 feet (60 to 92 meters) above sea, contains considerable quantities of Eocene coal, probably transported from the outcrops near Renton, but none was observed in the Admiralty till. This horizon of the Admiralty till is traceable for several miles to the north and to the south.

To the section observed on Carbon river, in which all the principal formations have been recognized, the base consists of bluish sandy clay, minutely stratified and dipping 15 degrees to the east. The deposit includes occasional gravel lenses and passes into fine sand on the top. Its altitude is from 460 to 500 feet (140 to 152 meters) above sea. This stratified deposit may perhaps be correlated with the Admiralty till, as representing a portion of that material which has been redistributed by subglacial waters.

In thus reciting the occurrences of the Admiralty till and clays I have followed Russell in correlating them. They are, however, markedly diverse in structure, the till having that structureless character peculiar to material spread beneath massive ice, whereas the clays are very uniformly and very evenly stratified after the manner of fine material deposited in deep water. The transition from the unstratified to the stratified masses may indicate the simultaneous occurrence of ice-tongues enclosing water bodies of considerable depth. It may be, however, in some cases at least, that the stratified and unstratified materials were not contemporaneously deposited and should be separated in a logical classification. In order to give them distinctive names it appears desirable that the term "till" should be restricted to the unstratified deposits, and the simple term clays be applied to the stratified formations.

The formations of the Admiralty epoch are so slightly represented in the area which I have studied that I do not feel qualified to discuss its history. Russell's observations indicate that the record is not simple, and it appears to be possible that more detailed study may show the existence of more than one till below the Vashon. The present report is to be considered as a preliminary statement only, and all its conclusions are set forth provisionally and subject to correction by more extensive field work.

Summary

The Puget Sound basin occupies a geosyncline of Eocene-Miocene development between the Cascade and Olympic mountain ranges.

Within the drift-covered area of the Sound the topographic features fall into two classes according to magnitude, namely, (1) major features consisting of the hollows, which are inlets, and the plateaus; and (2) minor features of glacial and aqueous origin.

To account for the peculiar physiographic type of Puget sound, two hypotheses are suggested—the erosion hypothesis and the construction hypothesis.

The erosion hypothesis: As a result of general glaciation, the Puget Sound basin was filled with drift up to an approximately even plain. With retreat of the ice after one or several epochs of glaciation, streams were established, which cut their channels in the drift down to a level represented by the depths of the Sound. In consequence of depression of the region, the valleys were submerged and the present inlets established.

The construction hypothesis: Glaciation of the Puget Sound basin was confluent, not indigenous. The distinction is important in its bearing on the effects of advance and retreat of the ice. Where glaciation is indigenous the accumulation begins at high altitudes, and the summits are covered with névé before the lower valleys are filled with ice. In the epoch of lessening glaciation the summits are last bared; but where glaciers become confluent in a region in which they do not originate, the valleys are first occupied and filled, and the hills are subsequently buried. When the ice-mass diminishes, the hilltops are laid bare while yet the valleys are the seats of glaciers. Glaciers first occupied the valleys of the Sound basin, but becoming dammed rose till the ice overtopped divides. During the episode of retreat hilltops appeared as nunataks, and this condition extended to divides. In ponded waters about these nunataks accumulated stratified drift. Stagnant ice lingered in the valleys to the latest stages of retreat, and, melting, perpetuated their relations to the heights. By repetitions of this process the antecedent divides were built out to plateau forms, and the axes of the original valleys were maintained as relatively shallow hollows, which are thus the casts of glacial tongues. Oscillations of level and the effects of erosion played a subordinate part.

The distribution and depths of the hollows apparently do not correspond to those relations which should exist if the inlets were drowned.

Consideration of the post-Pleistocene work of streams shows that the effects of corrasion are very slight as compared with the magnitude of the hollows.

The White River alluvial cone is so adjusted to sealevel as to indicate that oscillations of regional extent have been very moderate during post-Glacial time.

The glaciation of Puget Sound basin was the confluence of ice-streams from three sources, namely: (1) A northern ice-sheet which flowed over the San Juan archipelago and westward through the straits of Fuca, but sent a massive glacier southward into the depression between the Cascades and Olympics; (2) the Cascade range in Washington, and (3) the Olympic range. These are named in the order of magnitude, the northern ice-mass having been much the greatest.

The name Vashon is given to the till distributed by the northern glacier during the latest glacial epoch, and the term is extended to the epoch.

Along the Duwamish valley lateral moraines prove that the valley antedated the latest epoch of glaciation and is not a channel of post-Pleistocene erosion. Similar evidence extends the inference to certain other valleys.

Deltas on the slopes to the Duwamish valley and others at higher level show that the Vashon ice served as a dam at various stages of its retreat and ponded waters in topographic embayments.

Various topographic features, terraces, pitted plains, sterile washed plains, and channels are attributed to the vicissitudes of streams during glacial retreat and to the interaction of ice tongues and rivers.

The Vashon drift is prevailingly of sandy loam and coarse rounded gravel. Its character and the topographic forms to which it gives rise prove that it was distributed extensively by glacial and subglacial streams.

The topographic effect of the Vashon ice advance and retreat was to build up the plateaus particularly about their margins, to establish inward-flowing drainage systems, and to narrow the major hollows. The effect was to build up previously existing major features. The glacier did not obliterate the valleys under an even mass of drift.

A till, called Osceola, which is characterized by rocks from the Cascades and their foothills, is recognized as distinct from the northern Vashon till. Its relative distribution and its relation in time to the Vashon till are described. The Cascade glacier spread this till before the ice-sheets became confluent, and osars of Vashon drift developed on it.

Certain coarse gravel beds which underlie the latest glacial formations are identified as being stream deposits with ice carried boulders. They are correlated with the advance of the glaciers of the Vashon epoch. Though local, they typify deposits which may probably occur elsewhere.

An unconformity by erosion is recognized and is used to distinguish formations of the Vashon glacial epoch, above, from those of an interglacial epoch, called Puyallup, below.

The formations of the Puyallup interglacial epoch are stratified gravels and sands, being deltas and relatively deeper water deposits. They exhibit synclinal and faulted structures which are attributed to the melting of included ice-masses. They are also correlated with widespread and thick lignite beds. From these facts it is inferred that the gravels were superglacial and bore a forest growth over stagnant ice, as is now the case with the marginal moraines of the Malaspina glacier. The sands overlying the gravels accumulated in deep waters, probably ponded by the northern ice.

Beneath the city of Tacoma is a complex mass of gravels exhibiting plunge structure and faults. The deposit is attributed to the outflow from a lake which covered Steilacoom plains as the ice retreated from the immediate vicinity. The delta formed during the Puyallup interglacial epoch and was added to during the withdrawal of the Vashon ice.

The lowest deposits observed in the southeastern part of the Sound basin are blue clays, in some places stratified, elsewhere structureless and containing many rounded and angular stones. These are both considered to be formations due to the spread of an ice-sheet earlier than the Vashon, from which it is separated by the Puyallup interglacial epoch. This earlier glacial epoch is named from Admiralty inlet, and its formations are designated the Admiralty clays, stratified, and the Admiralty till. The Admiralty epoch was one of general glaciation in the Sound basin. It is possible, if not probable, that it was preceded by other epochs of interglacial and glacial conditions, which further study may distinguish.

The classification of epochs and formations herein described is provisional and may be modified by further detailed observation. The paper is published to afford a working hypothesis for those who may enter this field of complex drift phenomena. Its basis in observation is not broad enough to give it conclusive value.

SECTION A.

Locality.—Bluffs, north bank of Carbon river, 3 miles northwest of Carbonado, measured by aneroid barometer, ascending along southeast edge of nearly vertical face. Read from the bottom upward in the order of relative age.

Ele. above sea.	Character of material.	Structure of deposit.	Conditions of deposition.	Probable correlation.	Formation name.
Feet. 740	Gravel and sand under humus, forming a generally level surface, with occasional kettles; a section of a kame terrace.				
705 to 740	Coarse gravel, well rounded; numerous large pebbles of quartz and granite; boulders up to 2 feet in diameter.	Irregularly stratified with sandy lenses.	Swift currents of loaded glacial streams at and under the ice-margin.	Vashon epoch: early stages of ice retreat.	Vashon drift.
655 to 705	Clay and very fine sands, bluish, weathering dark brown.	Horizontally stratified in layers 3 inches to 6 feet thick; horizontally ribbed on weathered face.	Still water, supplied with sediment from glacial sources.	Vashon epoch: Osceola till; stage of advance of the Cascade glacier prior to its complete confluence with the Vashon ice, and while the two ice-sheets enclosed a water body in this locality.	Osceola clays.
615 to 655	Coarse gravel; pebbles up to 6 inches in diameter, finer toward the base.	Generally stratified, with gentle dip, somewhat cross-stratified; coarse and fine materials mingled.	Swift currents of loaded streams, probably fed with glacial debris.		
605 to 615	Coarse gravels, enclosing subangular boulders up to 4 feet in diameter.	Stratified	Temporary flooded state of streams carrying ice-masses and boulders in them.	Vashon epoch: advance of the Rainier ice with streams building coarse deltas before it.	Douty gravels.
600 to 605	Gravels, relatively finer than those above, but with pebbles up to 6 inches in diameter.	Stratified and cross-stratified; coarse and fine materials mingled.	Swift currents of loaded streams, flowing probably from glacier on the south.		
600	Unconformable contact of gravels on eroded surface of sands			Interglacial epoch.	
560 to 600	Sands, loose, incoherent, forming talus; upper surface irregular, varying 1 foot to 5 feet from its general plane.	Strongly cross-stratified; dip 20° southwest; edges of layers come up to the contact.	Delta building by a stream swiftly flowing southwest, carrying finer materials further into a water body.	Admiralty epoch: stage of retreat while yet the ice dammed the northern outlets and held a local water body here.	Puyallup sands.
545 to 560	Coarse gravel, finer below, grading up to pebbles 10 inches in diameter above, orange colored.	Stratified	Swift currents of loaded streams spreading in shallow waters or deltas, or distributing superglacial material.	Admiralty epoch: stage of retreat; fluctuations of the streams and ponded waters, affording alternations of conditions of deposit; climate relatively mild; oxidation of ferruginous solutions; lignite horizon.	Orting gravels.
530 to 545	Homogeneous sands, coarse as compared with those above 560 feet, orange colored.	Stratified			
505 to 530	Gravels, coarse and fine, interbedded, up to 6 inches in diameter, orange colored.	Strongly cross-stratified; dip 20° to 25° east.			
460 to 505	Blue clay, sandy, including gravel lens, fine sand on top.	Minutely stratified; dip 15° east.	Gentle currents flowing from the ice and depositing sediment derived from the till.	Admiralty epoch: stage of retreat; early ponded waters. If the ice advanced so far south as this at this point the till probably lies below.	Admiralty clays.

Section B.

Locality.—East side of the Puyallup valley at Orting; section observed along the road grade.

Elevation above sea.	Character of material.	Structure of deposit.	Conditions of deposition.	Probable correlation.	Formation name.
Observations begin at the highest exposure of sands beneath the Vashon drift, which forms the summit of the hill and extends 200 to 300 feet down the slopes.					
Feet. 640 to 900	Vashon drift, coarse rounded gravel and loam, with large boulders; no eastern or southern drift seen.	Confusedly mingled, occasionally stratified, heaped in ridges trending northwest about Orting lake.	Subglacial by combined action of ice and streams.	Vashon epoch: during stage of confluent glaciation.	Vashon drift.
410 to 640	Prevailingly uniform sand, fine, occasional pebbles up to 1 inch in diameter, incoherent, no bodies of gravel.	Probably concealed by sliding; material is water sorted and probably stratified in place; no definite bedding observed.	Swift currents depositing cleaned sands, a delta formation, from a copious source.	These sands and gravel lenses apparently form a delta of a large stream which gathered from the sources of White river. The deposit may correspond with the Douty gravels and the Puyallup sands, both, being divided by an unconformity, or it may be wholly either one or the other of these formations. The section is generally covered by sliding sands.	
410	Gravel in sands, rounded pebbles up to 5 inches in diameter, one angular stone 1 foot in diameter in gravel at the upper contact.	None observed; exposure very limited.	Probably a local deposit from a swift current, possibly with ice.		
340 to 410	Sand prevailing, with layers of gravel irregularly distributed.	Obscurely stratified..................	Swift currents, possibly from different directions.		
200 to 340	Coarse gravels, boulders, gravel, and sand, orange colored, heterogeneously mingled, firmly cemented, granite boulders occasionally decomposed.	Locally stratified; generally without definite structure.	Swift currents of loaded streams spreading morainic material over and around stagnant ice.	Admiralty epoch: episode of retreat; mild climate favoring ferruginous solution; no lignite seen.	Orting gravels.
200	Level of the bridge across the Carbon river.				

SECTION C.

Locality.—West bank of Puyallup valley, 4½ miles north by west from Orting. Read from the bottom upward in the order of relative age.

Ele. above sea.	Character of material.	Structure of deposit.	Conditions of deposition.	Probable correlation.	Formation name.
	The margin of the plateau presents a very irregular slope toward the east, descending from a ridge (elevation, 530 feet to 540 feet) of very coarse gravel and loam across deep kettleholes to the escarpment, which is better defined.				
Feet. 300 to 535	Coarse gravel, with loam and large boulders.	Confusedly mingled...............	Beneath the margin of the ice which occupied Puyallup valley.	Vashon epoch: stage of retreat while the ice still overflowed on to the plateau.	Vashon drift.
360	Edge of very steep slope, sometimes vertical, to the valley.				
250 to 360	Gravels, well exposed only below 275 feet, relatively fine and coherent.	Stratified up to 275 feet and perhaps higher.	Swift currents of loaded streams.	Vashon epoch: stage of advance, with streams building in front of the ice.	
240 to 250	Gravels, with sand lenses, enclosing boulders up to 5 feet across with sharp corners.	Sands stratified; gravels mingled irregularly.	Swift currents discharging sand and gravel into ponded waters, while floating ice carried in boulders.	Vashon epoch: stage of advance.	
240	Unconformity marked by sharp contact of coarse gravel deposits on level surface of fine sands; no erosion noted.			Interglacial epoch.	
230 to 240	Sands, very fine and uniform, consolidated to a coherent sandstone, bluish, with sandstone concretions; calcareous.	Horizontally stratified.............	Quiet waters, ponded by ice......	Admiralty epoch: the later stages of retreat.	Puyallup sands.
230	Fine shale, 2 inches thick.........	....	Quiet waters, ponded by ice......	Admiralty epoch: the later stages of retreat.	
222 to 230	Sands, more clayey than those above.	Horizontally stratified.............	Quiet waters, ponded by ice	Admiralty epoch: the later stages of retreat.	
219 to 222	Fine whitish clay, with minute bits of carbonaceous material.	Horizontally stratified.............	Quiet waters, ponded by ice	Admiralty epoch: the later stages of retreat.	
200 to 219	Sands, clayey, coherent, forming vertical bluff.	Horizontally bedded with overlying strata.	Quiet waters, ponded by ice	Admiralty epoch: the later stages of retreat.	
200	Top of talus slope. In adjacent exposures coarse gravels similar to those forming the lowest bed at Orting, orange colored and characterized by decomposition of the granite pebbles, are seen to occur up to about 160 feet above sea, and to extend down to the present alluvial plain of the valley.				Orting gravels.
100	Level of the alluvium, which floors the valley.				

SECTION D.

Locality.—East bank of the Puyallup valley, 4 miles north of Orting, 1¼ miles east of the preceding section.

Elevation above sea.	Character of material.	Structure of deposit.	Conditions of deposition.	Probable correlation.	Formation name.
Section exposed in a bank undercut by the Puyallup river, measured near the southern end of the exposure. Surface above is a slope of Vashon drift, with large kettleholes.					
Feet. Thickness.					
171	Top of cut bank.				
5 ft.	Coarse gravel with some loam, 1 inch to 6 inches in diameter, rounded and compact.	Irregular and confused.........	Subglacial or marginal........	Vashon drift.	
2 ft. 6 in.	Sand with much gravel; dark gray, fine.	Distinctly stratified; dip is nothing at each end of the long bluff, but the section exposes a syncline, with dips of 10° toward the center of the bluff; the strata are traversed by numerous normal faults which increase the depth of the syncline. The structure is that which the beds might assume if deposited on an ice-mass that slowly melted away.	Swift streams of variable power building a delta on the previous deposit of gravels which buried a stagnant ice-mass.	Admiralty epoch: water body retained by the ice.	Orting gravels or Puyallup sands?
6 ft.	Sand and fine gravel interstratified, layers 2 inches to 1 foot thick; gravel predominating.				
3 ft.	Sands, coarse and fine, minutely interbedded, enclosing occasional pebbles up to 3 inches in diameter.				
2 ft. 6 in.	Sands, enclosing pebbles along the lower contact up to 8 inches in diameter.				
1 ft. 3 in.	Gravel and coarse sand, pebbles ½ inch to 3 inches in diameter.				
1 ft.	Sand, coarse.				
1 ft. 3 in.	Gravel with much coarse sand.				
6 in.	Sand, coarse.				
2 ft.	Gravel, with pebbles up to 3 inches in diameter; finer below.				
2 ft.	Sand, coarse with fine pebbles.				
4 ft.	Gravel and coarse sand intimately interstratified.				
40 ft.	Coarse gravel, irregularly bedded with limited sandy lenses including boulders up to 10 inches in diameter.	Irregularly bedded, sharing also the synclinal structure of the upper beds.	Subglacial and marginal streams depositing gravels on stagnant ice.	Admiralty epoch: stage of retreat.	Orting gravels.
71 ft.					
100	Puyallup river.				

SECTION E.

Locality.—East bank of Puyallup-Duwamish valley, 9 miles north of Orting; bluff adjacent to the main road; supplemented by observations at higher levels on the road to lake Tapps, one-fourth mile northeast.

Ele. above sea.	Character of material.	Structure of deposit.	Conditions of deposition.	Probable correlation.	Formation name.
Feet. 600 to 335	Undulating, boldly ridged surface of coarse gravel, loam, and sand, with large boulders all of Vashon drift, forming the system of osars about lake Tapps and out to the margin of the plateau. The road to lake Tapps ascends the scarp along a narrow ravine, in which are delta terraces as follows:				
335 to 350	Sands, argillaceous and pebbly, resting on Vashon drift.	Stratified and cross-stratified...	Delta formation by stream flowing down the ravine into waters ponded by the glacier in the Duwamish valley.	Vashon epoch: stage of retreat when the ice had left the plateaus but filled the valley.	
255 to 335	Slope of the upper delta.				
230 to 255	Sands, argillaceous and pebbly, forming a delta surface like the upper one, but of later development.	....	....	A slightly later stage of retreat, when the ponded waters subsided to this level.	
205 to 230	Not exposed in section, slope of Vashon drift.				
205	Blue clay, finely sandy; thickness, 3 feet, in gravels.	Horizontally stratified...........	Deposit in ponded waters; material possibly derived from Osceola till.	Vashon epoch: stage of advance when the rising ice enclosed waters in front of the Cascade glacier; prior to confluence.	Osceola clays.
135 to 205	Slope of plateau scarp, Vashon drift, not exposed in section.				
135	Top of bluff adjacent to main road, south of the ravine.				
100 to 135	Coarse gravel, pebbles 1 inch to 15 inches in diameter, with loam and sandy lenses.	Horizontally bedded and cross-stratified.	Swift streams building gravelly delta in front of the ice.	Vashon epoch: stage of advance prior to confluence with the Cascade ice.	
100	Surface of sands, irregular, eroded	....	....	Interglacial epoch.	
90 to 100	Fine sands, with gravel lenses, and compact gray clay.	Strongly current bedded	Swift streams loaded with much sediment and some coarse gravel building deltas.	Admiralty epoch: stage of retreat while the ice held ponded waters.	Puyallup sands.
82 to 90	Coarse gravels; pebbles 1 inch to 5 inches in diameter, with sandy lenses.	Horizontally stratified and cross-stratified.	Swift streams loaded with gravel.	Temporary condition favorable to transportation of coarse material.	
75 to 82	Fine sands, uniform, coherent, without calcareous cement.	Indistinctly bedded	Currents depositing in water too deep to permit current bedding.	Admiralty epoch: stage of retreat while the ice confined waters.	
75	Level of the main road.				

SECTION F.

Locality.—South bank of Green river, 9 miles east by south from Auburn; section measured on road descending from the plateau to a bridge across Green river.

Ele. above sea.	Character of material.	Structure of deposit.	Conditions of deposition.	Probable correlation.	Formation name.
	The surface to the south and east of this locality is relieved by ridges, 60 to 100 feet high, of coarse water-worn detritus mingled with sand and loam, enclosing extensive kettleholes and hollows. These are probably subglacial deposits or osars.				
Feet. 580 to 640	Coarse gravel and loam, forming a ridge on the edge of the scarp which slopes to the river.	Heterogeneously mixed, locally stratified.	Subglacial by cooperation of ice and streams.	Vashon epoch: stage of retreat of Cascade ice.	
580	Gap in the valley rim, leading to a wide swampy level to the southwest; a former outlet for a stream from the valley.	....	....	Vashon epoch: stage of retreat subsequent to the deposit of subglacial gravels.	
560 to 580	Sands, coarse and fine, well washed, interstratified with clayey layers, 2 inches to 20 inches thick.	Horizontally bedded, wavy, with fine cross-bedding in sandy layers.	Quiet waters within range of fluctuating currents; glacially ponded waters receiving till sediment.	Vashon epoch: stage of advance prior to confluence of the Cascade and Vashon ice-sheets.	
530 to 560	Blue clay, sandy, very compact, numerous rounded pebbles ½ inch to 12 inches in diameter; angular stones of Eocene sandstone and shale, 18 inches to 3 feet on a side; till.	Not stratified, firm, homogeneous.	Subglacial by ice alone, movement from the east.	Vashon epoch: Osceola till of the Osceola tongue of the Cascade glacier.	Osceola till.
520 to 530	Boulders, 3 inches to 2 feet in diameter, irregularly distributed.	Locally indistinctly bedded, generally confused.	Marginal or submarginal to the ice.	Vashon epoch: moraine of the advancing Osceola tongue.	
520	Uneven, eroded surface of sands; unconformity	....	....	Interglacial epoch.	
490 to 520	Sands, interbedded with gravel lenses.	Stratified and cross-stratified; stream-bedded.	Quiet waters, receiving delta deposits from fluctuating streams.	Admiralty epoch: stage of retreat while the ice still ponded waters in the district south and west of its front.	Puyallup sands.
455 to 490	Sands, blue, clayey, compact, weathering brownish; weathered surface ribbed according to proportion of clay in the layers.	Horizontally stratified, jointed, exceedingly firm, almost consolidated to sandstone.	Quiet waters, receiving sediment, probably from streams corrading till beyond the zone of gravel deposition.	Admiralty epoch: stage of retreat while the ice held ponded waters.	Puyallup sands or Orting gravels?
240 to 455	Talus slope.				
240	Bridge across Green river.				

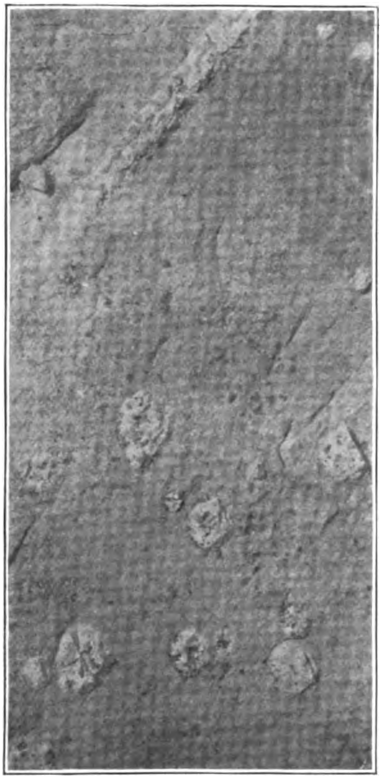


FIGURE 1.—SEPARATE NODULES AND A VEIN
(About one-tenth natural size)

FIGURE 2.—LENTICULAR NODULES ARRANGED IN ROWS
(About one-tenth natural size)

FIGURE 3.—SEPARATE NODULES AND FORKED, VEIN-LIKE MASS

NODULAR GRANITE FROM PINE LAKE, ONTARIO

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 9, PP. 163-172, PL. 11 FEBRUARY 10, 1898

NODULAR GRANITE FROM PINE LAKE, ONTARIO

BY FRANK D. ADAMS

(Read before the Society December 30, 1897)

CONTENTS

INTRODUCTION

While engaged during the past summer in carrying out some work for the Geological Survey of Canada in the eastern portion of the province of Ontario, a somewhat remarkable occurrence of orbicular or nodular granite was met in the township of Cardiff, in the county of Peterborough, which, on account of some peculiarities it presents, seemed worthy of detailed study.

This part of eastern Ontario is underlain by rocks of Laurentian age, which here consist chiefly of crystalline limestones with rusty weathering gneisses and amphibolites, broken through by great intrusions of granite, the geological relations being very complicated and intricate, as the mapping of the area now in progress shows.

GENERAL DESCRIPTION OF THE OCCURRENCE

About halfway across the township of Cardiff and near its southern limits is Pine lake, a body of water some two miles long and averaging about a quarter of a mile in width. The bold rocky shores of the lake are formed of a rather fine grained reddish granite, except at the northern and near the southern extremity, where the granite is associated with a dark gabbro-like amphibolite, through which it apparently cuts. The granite is in many places quite massive, but usually shows a somewhat gneissic structure, marked chiefly by the presence of small and ill defined but rudely parallel streaks, differing from one another somewhat in size of grain. Where this gneissic structure is seen, it coincides in direction with the strike of the associated amphibolitic rock, which in places is also foliated. Much of the granite resembles aplite in appearance, but in places it passes into a coarse pegmatitic development, holding large masses of black schorl. Its general character, except for these minor variations, is uniform over a very considerable tract of country, and its appearance is that of an undoubted igneous intrusion.

The nodules described in the present paper do not occur throughout the whole mass of the granite, but are confined to a portion of it, which, although situated toward the northern limit, is from 200 to 300 yards from its contact with the amphibolite, so that the nodular development cannot be regarded as a contact phenomenon. Along the contact, the granite is in fact free from nodules. The localities where the nodules have been found are all situated on Range III of the township of Cardiff, being chiefly on Lots 13 and 15, which lie opposite to one another on the north and south sides of Pine lake, respectively. They are also found to the northeast of the lake, at a point probably about Lot 18 of the same range. In these localities the nodules are abundantly disseminated through the rock, although not thickly crowded together as in many other similar occurrences elsewhere described. Where most abundant 200 were counted on a surface 36 square feet in extent. Elsewhere they are much less numerous.

They are usually spherical in form, but in some places have a more or less flattened or elliptical outline. This is more especially the case where the granite shows a tendency to foliation, the longer axes of the nodules in this case being parallel with the strike of the rock (see plate 11, figure 2). The nodules have a diameter of from one to eight inches, but usually measure from two to three inches across and can readily be broken out of the rock entire and almost free from the surrounding matrix. Those of them which have been cut across and smoothed by the glaciation of the country show the inner portion of the nodule to be lighter in color than the normal granite.

Being harder and more resistent than the granite, furthermore, they stand out a little from its somewhat disintegrated surface. Many of the nodules when thus ground flat by the action of the ice also exhibit a more or less distinct zonal structure, the central portion being somewhat different in composition from the exterior, although this is not always seen. There is, moreover, usually a little bunch or sponge of black tourmaline near the center, while large glistening poikilitic plates of muscovite are often seen.

Although throughout the greater part of the area in which they occur these nodules are scattered haphazard through the rock without any definite arrangement, in one or two places they were found arranged in rows. The nodules in such rows vary somewhat in diameter, though not greatly, and are at first separated by an interval of two or three inches. On following along the line, however, they are found to come closer together and then to form a continuous string, touching one another, the long row of contiguous balls being here and there interrupted by spaces of the normal granite. Still further on, as indicated in figure 1, the

FIGURE 1.—*Vein passing into separate Nodules.*

One-fiftieth natural size.

nodules of the row are found to fuse or coalesce, at first into a series of sausage-like masses and then into a continuous band, having the width of a single nodule, a band which as exposed on the glaciated surface of the rock no observer would hesitate to regard as a true vein filling a fissure, could not its passage into the separate nodules be distinctly traced (see plate 11, figures 1, 2, and 3). These "veins," moreover, in some cases show a rude banding parallel to the walls, for the concentric structure of the nodules passes naturally over into the banded structure of the vein. The quartz which is more abundant in the outer portion of the nodules is thus more abundant on the sides of the vein, while muscovite and feldspar, being more abundant toward the center of the nodules, are also more abundant toward the middle of the vein. The relation of the "vein" to the series of spherical masses, moreover, is indicated by the successive little sponge-like bunches of tourmaline rounded in general outline, like those found toward the central part of the nodules, which are distributed along the length of the vein at more or less regular intervals (see figure 2). In some cases even traces of the medial line can be seen on the weathered surface, passing down the length of the vein and suggesting the meeting place of the combs in the combed vein (see plate 11, figure 1). These "veins" are well defined against the granite, although the boundary is not absolutely sharp, and occasionally they split and fork as other veins do, and pass into a row of nodules (see plate 11, figure 3). Their continuity in depth could not be so well studied, as they are exposed chiefly on horizontal surfaces. In one instance, however, on the face of a little cliff, one of them could be seen to extend vertically through the granite in a direction at right angles to its strike for a distance of three feet and then downward out of sight. It is certain

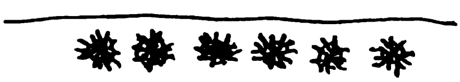


FIGURE 2.—*Sponge-like Bunches of Tourmaline.*

Arranged at intervals along a vein. One-fifth natural size.

from this and numerous other observations that these "veins" do not represent merely single lines of nodules, but rather sheets which fray out into separate nodules along their outer margins.

Whether irregularly disseminated through the rock, as is usually the case, or whether arranged in lines or sheets, as in certain rare instances, the nodules bear a striking resemblance, so far as mode of occurrence is concerned, to the spherulites, axiolites, and other similar structures seen in obsidian and other volcanic rocks, although, of course, on a very much larger scale (see plate 11, figure 2).

The several structures described can be duplicated on a small scale in many hand specimens of the obsidian from the Yellowstone park. The presence of tourmaline and muscovite is suggestive of the presence of mineralizers, which also play so important a part in the formation of spherulites. These nodules, however, differ in a marked manner from such spherulites in that their composition is not identical with that of the enclosing rock, while in the case of the spherulites there is a practical identity in this respect. That an abundance of mineralizer was present in certain parts of the granite magma is, however, indicated by the streaks or more or less irregular segregations of coarsely crystalline quartz and tourmaline found in places through the rock.

Microscopical Character of the enclosing Granite

The red granite from various parts of the area is found when examined under the microscope to be uniform in composition and microscopical character, although, as has been mentioned, varying somewhat in grain. Orthoclase and microcline preponderate largely, the former in untwinned grains, showing good cleavages, the latter presenting a well marked cross-hatched structure. Soda-lime feldspars are also present, although in very subordinate amount. The microcline, which is usually about equal to the orthoclase in amount, is in some places present in large grains with irregular boundaries and a marked micropoikilitic structure, the enclosed grains consisting of orthoclase, plagioclase, and quartz, with a few of biotite and iron ore. These inclusions, which are often very numerous, are more or less rounded in form, their outline being often nearly circular. They are also quite irregularly oriented. The microcline in these cases is evidently younger than the other constituents of the rock, with the possible exception of the quartz, as has been found to be the case with this mineral in a number of granites which have been recently studied.

The quartz is much less abundant than the feldspar and often occurs in subpolygonal or more or less rounded grains, instead of occupying the interstices between the other minerals as in a normal granite, a mode of occurrence which marks an approach in character to that seen in the granite porphyries. Highly pleochroic biotite is present in considerable amount in the usual lath-shaped forms. A small amount of muscovite, often intimately associated or intergrown with the biotite, is also present. This mineral also occurs enclosed in the feldspars, either as well defined individuals or in grains having the peculiar feathery, fretted, or lace-like margins exhibited by it in certain other granites, and in such cases it often has an edging of quartz surrounding a portion of it. In some cases it was even observed enclosed in quartz. A few grains of iron ore and apatite complete the list of minerals found in the rock.

Microscopical Character of the Nodules

Six nodules were selected for microscopical study, and eight sections, each comprising a whole nodule, were prepared. Three of these nodules, when cut across, showed a rather distinct concentric structure, the outer and inner portions differing somewhat in color, the former consisting chiefly of quartz and sillimanite and the latter chiefly of quartz and muscovite. The outer and inner portions, however, are not separated by a sharp line, but fade into one another, so that no satisfactory separation of them for purposes of chemical analysis could be effected. Many nodules also, as has been mentioned, when broken across, show a small sponge-like mass of black tourmaline toward the center. In the case of the other three nodules this zonal arrangement was merely suggested, the nodules being essentially uniform throughout. One of them, however, contained the tourmaline sponge, before referred to, near the center, and in two of them there was an indistinct tendency to a radial arrangement on the part of some of the constituents.

The absence of pronounced concentric or radial structure is one feature in which these nodules differ in a marked manner from the basic concretions, nodules, and varioles described in other granitic rocks. On passing from the granite to the nodule there is seen under the microscope an abrupt change both in grain and composition. The regular mosaic of the granite is replaced by a coarser grained and sometimes indistinctly radial or sheaf-like arrangement of the constituents; the biotite and microcline disappear entirely, while the quartz and muscovite, especially the former, become more abundant, and sillimanite makes its appearance, usually in large amount.

Quartz, muscovite, and sillimanite are the chief constituents of the nodules. Plagioclase and an untwinned feldspar, probably orthoclase, which are present in some nodules in considerable amount, but in others in very small quantity, with tourmaline in some cases and a few grains of iron ore and pyrite, complete the list of constituent minerals.

The quartz is uniaxial and forms a well defined mosaic of polygonal grains, showing little or nothing of the tendency to develop rounded individuals seen in the granite itself. It often holds an abundance of sillimanite needles, although in it this mineral does not usually occur in such mats as in the feldspar. It frequently contains lines of minute cavities, some of which enclose moving bubbles. The muscovite occurs in large colorless plates, often of very irregular outline, extending in some cases completely across the central portion of the nodule, and holding many inclusions of quartz, sillimanite, and other constituents. The irregular and indented outline is quite distinct in appearance from the finely fretted or lace-like boundary presented by the muscovite of the granite, the outlines being quite sharp. It may, however, be regarded as this structure on a much larger scale. It has the eminent basal cleavage characteristic of this mineral, with the uniform extinction parallel to it.

The sillimanite occurs in long, slender, isolated needles with transverse partings and extinction parallel to their length, or as bundles or mats of such needles, felted into nearly opaque masses. It occurs penetrating both the quartz and muscovite, but, as has been mentioned, is especially abundant in the feldspar, which is usually crowded with needles of it. The sillimanite individuals are usually very small, and are irregular in cross-section. There is, however, a tendency to develop the nearly square or the eight-sided prismatic forms usually seen in this species, and the larger grains show the usual good cleavage in the direction of one pinacoid. The mineral is uniaxial and positive, and $c = \mathfrak{c}$.

In one or two instances an individual of muscovite could be seen at its extremity to pass into a bundle or brush of sillimanite fibers.

The occurrence of sillimanite in granite, except along sheer zones, is, so far as I am aware, unknown, but the mineral often abounds in the quartz which occurs in veins and irregular masses in highly altered rocks in the vicinity of granite intrusions and elsewhere. Whether such veins have any genetic relation to such occurrences as those described in the present paper is a question for future investigation to decide.

The feldspars are present in some nodules in a considerable amount; in others they are practically absent. When present they consist in part of well twinned plagioclase and in part of an untwinned feldspar, probably orthoclase. Microcline is never found in the nodules, although it may abound in the surrounding granite. The feldspar, especially the orthoclase, occurs in irregular shaped individuals having the feather-like forms seen in spherulites, often with an indistinct radial arrangement, and sometimes showing a granophyric intergrowth with the quartz. It is not especially abundant in any part of the nodule, and is crowded with bundles and mats of sillimanite needles. The iron ore, which is black and opaque, occurs in each nodule in the form of a few rather large grains. A grain or two of pyrite is also usually present. The tourmaline, thus far found, occurs as a bunch of grains irregular in shape, dark in color, and with strongly marked pleochroism in pale gray and dark gray-blue tints. It is uniaxial and negative, and is associated with quartz and feldspar, and in one or two cases was seen to be penetrated by a few sillimanite needles.

Chemical Composition of the Granite and of the Nodules

In order to make a comparative study of the chemical composition of the granite and the nodules, a specimen was selected consisting of the typical granite in which there was enclosed a nodule spherical in shape and two inches in diameter. The specimen was broken up and the granite, excepting that immediately surrounding the nodule, was crushed and an average sample of it drawn. The nodule, after having been very carefully freed from the adhering granite, was broken across and one-half taken for analysis. The analyses were in each case carried out in duplicate, the figures given below representing the mean of two closely concordant determinations:*

	Granite.	*Nodule.*
Silica	78.83	81.43
Alnmina	10.88	13.70
Ferric oxide	1.63	1.58
Lime	.22	.37
Magnesia	.35	.06
Potash	5.31	1.28
Soda	2.13	1.02
Loss on ignition	.32	.92
	99.67	100.36

Boracic acid was not looked for. The silica in a second nodule was found to amount to 79.19 per cent.

The analyses bring out the fact that the granite is a very acid one, and that the chief difference between it and the nodules is that the latter are richer in silica and alumina and poorer in alkalies than the granite itself. Among the minor differences is the marked preponderance of potash over soda and, owing to the presence of the biotite, the larger percentage of magnesia, in the case of the granite.

A study of thin-sections of this particular specimen of granite showed it to be composed chiefly of quartz and microcline, with a small amount of biotite, plagioclase, and an untwinning feldspar, probably orthoclase. Very small amounts of muscovite and iron ore were also present.

The exact composition of the several minerals present not being known, it is impossible to calculate the percentages in which they are found in

*They were carried out in the laboratories of McGill University by Mr Nevil Norton Evans.

the rocks. By neglecting, however, those constituents which do occur in very subordinate amount and having in view a feldspar in which the alkalies are present in the proportion indicated by the analysis, a rough calculation shows that the granite is composed approximately of 42 per cent of quartz and 58 per cent of feldspar.

Similarly, in the case of the nodule, if all the alkalies are calculated as feldspar and the excess of alumina is calculated as sillimanite, the percentage composition would be approximately: quartz, 68 per cent; feldspar, 15 per cent; sillimanite, 17 per cent. If muscovite be present this will alter the relative proportions of these constituents, although not greatly, as the muscovite present cannot amount to more than a few per cent.

Origin of the nodular Structure

Granites and allied rocks containing spheroidal or concretionary lumps or nodules are known from many parts of the world and some of these occurrences are widely celebrated, as, for instance, the concretionary granite from Fonni in Sardinia, the "pudding granite" of Vermont, and the orbicular diorite of Corsica.

The origin of these structures is not, however, in all cases thoroughly understood; but in a recent and elaborate memoir* on the subject von Chrustschoff has presented the results of a very detailed comparative study of a large number of such occurrences and believes them to be genetically divisible into four groups.

1. Concentric, spheroidal, and concretionary growths about foreign inclusions.

2. Nodular growths about fragments of secretions or inclusions, which latter are often partially or wholly redissolved.

3. Group of the so-called pudding granites, where the structure is due to a simple concretionary action set up in the magma during its normal crystallization.

4. Primary structural forms of the magma or endomorphic contact products.

In the Pine Lake occurrence we evidently have to do with the case of primary magmatic differentiation, for although in the case of the occasional vein-like forms the mode of occurrence is such as to suggest a development subsequent to the crystallization of the granite, the fact that these pass into spherical nodules precisely identical with those which occur scattered as isolated individuals through the rock far and wide, and which are far more abundant than the streaked or vein-like forms, proves that they are both identical in origin and are derived from the crystallization of a magma which was free to gather itself into rounded

*Memoires de l'Academie Impériale des Sciences de Saint Pétersbourg, vii série, tome xlii, no. 3, 1894.

drop-like forms which the isolated portions of such a liquid would take, but which could not be developed in a magma when crystallization was far advanced. The constituent minerals of the nodules furthermore are not identical with the last formed constituents of the granite, as they should be if the nodules represented the last products of the crystallization of the granite magma. Microcline, which is abundant and one of the last minerals to separate out of the magma in the case of the granite, is entirely absent from the nodules, while sillimanite, which is never found in the granite, is one of the most abundant constituents in the nodules as well as one of the first of the constituents to crystallize.

The peculiarity of the present occurrence lies chiefly in the fact that the portion of the magma which thus separated out was more acid than the magma as a whole and richer in alumina, which is very unusual. It must be remembered, however, in this connection that the granite itself is more acid than usual.

Magmatic differentiation has been put forward by Bäckström to account for the origin of the nodular granite found at Kortfors, in Sweden,* in which, however, the nodules are more basic than the granite itself, as well as to account for other allied occurrences. He thinks that "it is in many cases evident that the inclusions were *soft*, and then the simplest view is that they were drops or portions of a partial magma, which, at the temperature existing immediately before crystallization, could no longer be held in solution by the principal magma but separated out." †

This seems to be the only satisfactory explanation of the Pine Lake occurrence, the history of whose development seems to have been as follows: In the original magma there were certain "schlieren" richer in silica and alumina than the rest of the magma, and containing also a certain amount of boracic acid. How these came into existence, whether by segregation or separation from the immediately surrounding magma, or whether brought into their present position from another part of the mass by movements in the molten magma, is uncertain. We have, however, examples of such differentiation in granite magmas in the case of pegmatite veins, which at their extremities frequently run out into veins of quartz associated with a little tourmaline. These schlieren, being evidently immiscible with the main mass of the magma, were analogous to globules, streaks, or sheets of oil in water, except that the magmas, being much less mobile than these fluids, the schlieren could not so readily run together into globules or rounded masses; or they might be compared with the globulites which separate from a solution which is about to crystallize and which, after appearing separately, aggregate themselves together into rows like strings of beads and eventually develop into va-

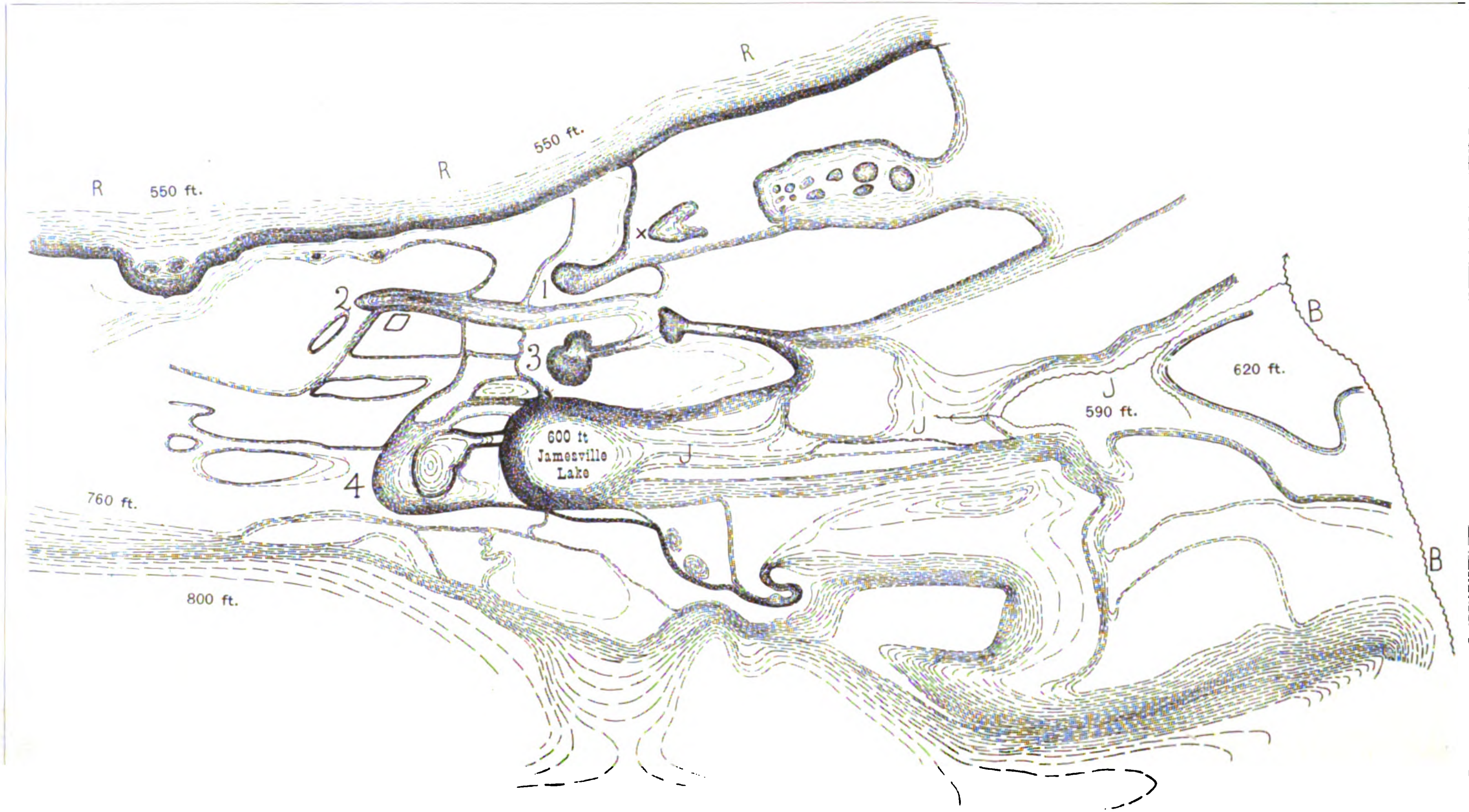
* Trenne Nyupptäckta Svenska Klotgraniter. Geol. Fören. i. Stockholm Förh. 1894, p. 128.
† Helge Bäckström: Causes of magmatic differentiation. Journal of Geology, vol, i, 1893, p. 778.

rious incipient crystal forms, as shown by Vogelsang and others in their experiments on the crystallization of sulphur. Any very small isolated schlieren that were developed through the magma or detached from the larger schlieren by movements in the semifluid mass would, of course, without encountering much resistance, take upon themselves a globular form, while in the case of larger streaks and sheets more resistance would be offered by the stiffness of the magma and the tendency to assume a globular form would be less pronounced.

When the magma had cooled sufficiently and crystallization began to set in, the solidification in the case of the granite followed the usual course, while the schlieren and globules, having a marked difference in composition, gave rise to different mineral combinations, and at the same time, perhaps on account of their peculiar chemical composition or perhaps because they contained a greater proportion of mineralizers, they developed during crystallization a tendency to spherulitic arrangement. In the case of the separate nodules, the crystallization seems to have started from the center and to have proceeded outwards, and, toward the extremity of the schlieren, to have commenced at a series of points along the medial line. The medial line of the schlieren thus corresponds to and is identical in character with the central portions of the nodules.

The possibility of the nodules having been produced by the melting down of portions of some fibrolitic band in the wall rock is eliminated by the fact that not only are such bands not found in the wall rock, this being everywhere a basic gabro-like amphibolite entirely different from the nodules in composition and character, but also by the zonal arrangement often observed in the nodules and their passage into the indistinctly banded vein-like forms which, as before mentioned, in some cases divide and fork, and are thus clearly not portions of the wall rock.

Whether any of the quartz veins so commonly found associated with granitic gneisses of undoubted igneous origin in the Archean or the quartz veins and strings, often rich in sillimanite, found abundantly in the altered rocks surrounding certain great granite intrusions of later date have the same primary origin as these in the Pine Lake granite is a question worthy of investigation; but the study of this occurrence shows that "contemporaneous veins" of an acid character may be formed not only during the final stage of crystallization, as in the case of the hysterogenetic schlieren and the "kluftblätter" of Reyer, but that highly silicious portions are sometimes segregated or differentiated out of a granite magma before crystallization, and that the banded structure often seen in pegmatites and other allied bodies and sometimes cited as proof of their aqueous deposition in preexisting fissures is not necessarily so produced, but, as is now being generally recognized, may and usually does result from the primary crystallization of the cooling magma.



MAP OF JAMESVILLE LAKE AND VICINITY, NEW YORK

J J J: Jamesville gorge at west end of which is Jamesville lake. *R R R*: Rock gorge. *B B*: Butternut creek. *1, 2, 3, 4*: Four dry channels, leading eastward to Butternut creek, with their associated kettle-form depressions. *X*: Transported quartzite, glacial boulder, resting on country rock.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 9, PP. 173-182, PLS. 12-14 FEBRUARY 17, 1898

TOPOGRAPHY AND HISTORY OF JAMESVILLE LAKE, NEW YORK

BY EDMUND CHASE QUEREAU

(*Read before the Society December 29, 1897*)

CONTENTS

INTRODUCTION

While among the lakes of central New York the narrow radiating lakes, known as the "Finger lakes," have received considerable attention at the hands of geographers and geologists, there are other classes of lakes in this region which have not as yet been made to any great extent the subject of serious study.

It is the purpose of this paper to call attention to one of a class of lakes which are conspicuously different in nearly all their topographic features from the "Finger" type of lakes, and which, by way of distinction from them, might be called "Round lakes," or, if they had not already a special meaning attached to them, the terms "Kettle" or "Pothole" lake would convey some idea of their most prominent characteristic. These lakes are usually round or broadly elliptical and occupy correspondingly shaped, isolated depressions in the surface topography. They are usually situated along the line of the minor valleys and occupy the less dissected portions of the plateau, between the main north-and-south valleys of this part of the state. They are of inconsiderable size—so small, in fact, that they often do not appear on the general maps of the state and must be looked for on the more detailed county maps or on the large-scale topographic maps of the government survey. Some of them are designated as "Green lake" or "Round lake" on these maps, the same term applying to several different water bodies. The lake near Jamesville which is the subject of this paper is not named on any of the maps which have come to my notice. At Jamesville and in the immediate vicinity of the lake it goes by the names "Green pond," "Green lake," and "Jamesville lake," indifferently, and I have chosen the name "Jamesville lake," as it helps to locate the lake and is the only one which distinguishes it from a number of other "Green" ponds and lakes. It is only a few hundred feet in diameter and is situated about a mile west of Jamesville and between five and six miles southeast of Syracuse.

The origin and history of this lake have been made the subject of more or less thought and speculation on the part of early geological and other writers who have described this region. The deep pit, or crater-like depression which it occupies, the remarkable symmetry of the lake and of its steep enclosing walls, and the unusual beauty of the ensemble when seen from a point of vantage, are such as to make a strong impression on the mind of the casual traveler or on the scientific student of nature. The theories advanced by the early observers are for the most part crude and readily disproven. Probably the most plausible explanation is the one which seeks to account for the lake on the supposition that it occupies the floor of a large cave, the roof of which had been so near the surface that it had fallen in, leaving the bottom of the cave exposed to view. This view is to a considerable extent current at the present time, and will be referred to again.

In December, 1896, Mr G. K. Gilbert, at a meeting of the Geological Society, called attention to the existence of a number of abandoned water channels in the vicinity of Syracuse which have a general east-and-west direction. These he believed to be the paths by which the Erian waters were discharged eastward across the state during the time when the Ontario basin and the Niagara outlet were still blocked by ice. This statement, which came to me some time after I had begun my studies about Jamesville, helped to solve two important difficulties which I had encountered, namely, that we have here large channels at right angles to the normal drainage of the country, and that at one time, as seemed to be clearly indicated, rivers of considerable size had occupied them. My studies led me to believe that the Jamesville lake basin and other similar depressions in the neighborhood should be associated in point of origin with these channels, as will be developed in the following discussion.

My study of Jamesville lake began soon after I came to Syracuse, in 1895. Since then I have spent considerable time, as occasion permitted, in the study of the topography of the lake and its vicinity. In order to represent the somewhat complex features of this region more clearly I constructed a topographic map of the lake and adjacent areas on the scale of 1:1500, which in reduced form faces page 174, as plate 12, and have reproduced photographs* of several of the localities referred to thereon (see plates 13 and 14).

The distances noted on the map were for the most part paced (a few were chained) and the heights were taken from aneroid readings with datum level some distance away, and are therefore only approximately correct. The broken lines are not contour lines, but are intended to represent approximately by their varying distances apart the steepness of slopes. By using a large compass and pacing most of the distances twice, the map has been made, it is believed, fairly accurate in its main features.

Before entering on a description of the lake and its immediate vicinity it will be desirable to give some account of the region which constitutes its larger environment.

General Features of the Region

Jamesville lake lies between two of the main valleys which dissect in this region the New York plateau in a general north-and-south direction. The valley to the west, which leads past Syracuse, is occupied by the Onondaga creek. The one to the east, which leads past Jamesville, is occupied by Butternut creek. They run approximately parallel to each other, from 3½ to 4½ miles apart, across the plateau northward, diverging rapidly after they leave it. They are broad, well defined valleys, and were plainly a part of the preglacial drainage system of the region, as their floors are filled deeply with glacial debris. This debris was not sufficient in amount, however, to entirely fill and obliterate the old valley, whose sides, composed of Devonian strata, still rise 200 and 300 feet above the present valley floor. The plateau block or spur separating the valleys of Onondaga and Butternut creeks is also covered with glacial debris, from a few to more than a hundred feet in thickness. For several miles south of Syracuse the glacial deposit capping the plateau takes the form of well developed drumlins, whose long axes have a general northwest-and-southeast direction, and whose bases merge together so that the country rock is almost everywhere concealed from sight.

The conditions so far described are thus seen to be comparatively simple and easy of interpretation. We have a plateau composed of nearly

* For these photographs I am indebted to the kindness of Mr C. E. Cummings.

horizontal strata which was moderately dissected in preglacial times by north-flowing streams. The plateau was overridden during the Glacial period by the ice, its valleys partly filled, and a mantle of drift spread over the parts of the plateau lying between them.

The general appearance of Jamesville lake and the character of the adjacent topography are well shown by plate 13, figures 1 and 2, which also indicate respectively the lake's outlet and inlet.

Transverse Valleys

The plateau block separating Onondaga and Butternut valleys is notched transversely by several smaller gorges or ravines, which in most cases run completely across the plateau from one valley to the other. I use the term notched because the floor of the transverse gorge or ravine is in most cases high above the floors of the valleys which they connect. For convenience I may designate in the following account the Onondaga and Butternut valleys as the *main* valleys in distinction from the transverse or *minor* valleys.

The transverse valleys run nearly at right angles to the main valleys—that is, nearly in an east-and-west direction. There are six transverse valleys of this sort connecting Onondaga and Butternut valleys, but in our study of Jamesville lake we shall be interested particularly in but two of them. The more northerly of these two is utilized by the Delaware, Lackawanna and Western railway to run across from the Onondaga into the Butternut valley. This is Rock gorge (see plate 12, *R R R*). The next one to the south leads past Jamesville lake to the village of Jamesville. It may be conveniently called the Jamesville gorge (see plate 12, *J J J*).

These two transverse valleys are distinguished sharply from the main north-and-south valleys which they connect in several important particulars. Two have been mentioned. First, that they run at right angles to the main valleys, and, second, that they are at a higher level. There may be added a third—that they are distinguished by the absence of all drift, both from the floor of the valley and from the top of their enclosing walls for a certain distance back from the valley margin, and, a fourth, that they are much narrower in proportion to their depth than the main valleys, as well as very much smaller in all their other dimensions.

The absence of drift in these valleys would indicate either that they were postglacial or that they had been scoured free of their glacial debris in Postglacial times. Their deepness and narrowness would indicate that they are relatively young. The sides of both valleys consist of perpendicular or steep rock walls with recent talus slopes concealing their bases.

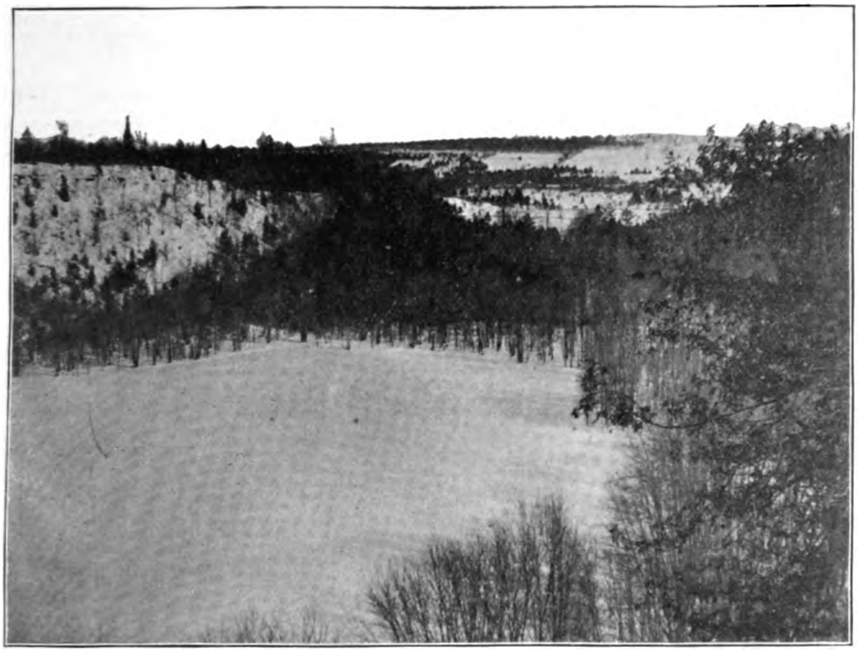


FIGURE 1.—VIEW OF EAST END OF JAMESVILLE LAKE

Showing lake surface in foreground and outlet of lake (at the right of the view)

FIGURE 2.—VIEW OF WEST END OF JAMESVILLE LAKE

Showing portion of inlet (upper left-hand corner of the view) and waterfall

VIEWS OF JAMESVILLE LAKE, NEW YORK

At the eastern end of each, where they debouch into Butternut valley, the valley wall is composed of a large amount of fragmental material arranged in terraces on the slopes toward the valley. This consists in very large part of sharp edged or imperfectly rounded pieces of Devonian rocks, such as occur in the immediate neighborhood, with which are mingled a few well rounded cobbles and boulders, evidently exotics of glacial origin. The rock floors of the valleys are concealed to some extent by accumulations of vegetal and of lacustrine origin, but one looks in vain for the characteristic boulder-clay which is found so plentifully everywhere else. Not only is this so, but the plateau surface between Jamesville gorge and Rock gorge, an interval of 1,200 to 1,400 feet, is swept clean of glacial deposits. The only trace of glacial visitation found consists of a well rounded quartzite boulder, varying in diameter from 2½ to 3 feet, which rests directly on the country rock about midway between the two gorges. It is striking on account of its unusual size.

Rock Gorge

Rock gorge (see plate 14, figure 1) has some special features of interest. It dissects the plateau the entire distance from Onondaga to Butternut valley. Its floor, which is quite level from side to side and from end to end, lies about 120 feet above the floors of Onondaga and Butternut valleys. It is noteworthy that the height of the floor of Rock gorge corresponds to the height of a well marked gravel terrace, apparently an old lake beach, which can be traced for several miles on both sides of Onondaga valley.

Rock gorge does not run straight across from one main valley to the other, but trends slightly southward as we pass from either end inward. It is thus, in the main map view, in the form of a very widely opened V, with its angle pointing southward. At the angle of the V—that is, about midway its length—and on the south side of the gorge the wall of the gorge is cut back in the form of an amphitheater, which is semicircular in outline and about 125 feet deep by 250 feet wide. The walls, as elsewhere in the gorge, are nearly perpendicular, with their bases concealed by recent talus accumulations. At the foot of the walls the floor of the amphitheater is depressed in a singular manner, or rather there is a series of pit-like depressions, such as might be found at the foot of a waterfall. The idea which suggested itself on my first visit to this place, that there had actually been a waterfall here, was enforced by finding later evidences of an old channel above, leading to the edge of the amphitheater.

Near the eastern end of the gorge, and with its head lying about in the middle of the gorge floor, is a trench, evidently of much more recent origin than the gorge itself, leading down from the gorge floor to the level of Butternut creek, 120 feet below. It is occupied and has apparently been formed by the waters flowing from a large spring near the head of the trench.

Other noteworthy features of this gorge are the evidences of the former existence of a lake near its western end and the large amount of delta-like accumulations at its eastern extremity. Well developed beds of shell marl and of stratified and undisturbed brick clay attest the fossil lake. The delta-like accumulations at the eastern end form the north wall of the valley for a considerable and the south wall for a short distance, and are distinctly terraced on the sides toward the gorge and toward the main valley. Thus we have additional evidence of extensive water action.

Jamesville Gorge

GENERAL DESCRIPTION

Jamesville gorge (see plate 14, figure 2), like Rock gorge, has a lake, not a fossil one, however, but one with water in it, near its west end, and terraced delta-like deposits at its east end. Its special features we will take up in the following order: 1. The fissures and caves in the vicinity of the lake; 2. The peculiar kettle-like depressions found in the neighborhood; 3. The channels which traverse in considerable numbers the surface of the region; 4. The terraces into which the sides of the channels are carved. We shall endeavor in this way to reach an interpretation of the topography of the lake and its surroundings, taken in connection with what we have already learned in regard to its remoter environment.

The drift mantle having been scoured from the surface of the country rock all about the lake and gorge, the character and topography of the latter can be readily noted on all hands. Its surface is seen to be flat or hummocky, and in the latter case it is smoothly rounded, not rough or jagged.

FISSURES AND CAVES ABOUT JAMESVILLE LAKE

An examination of the surface in this locality reveals the fact that it is traversed in many places by a remarkable network of fissures. These fissures are from a fraction of an inch to 6 or 8 inches in width, and extend nearly perpendicularly downward, sometimes to great depths. By letting down a stone attached to a line, a depth of 40 feet has been measured. It is evident, however, for other reasons that they are much deeper than this in places. A study of the rock *in situ*, in hand specimens and under the microscope, has led to the belief that these fissures develop along the joint structure of the rock. The joints are filled with smaller and larger veins of calcite or aragonite, and minute clefts are

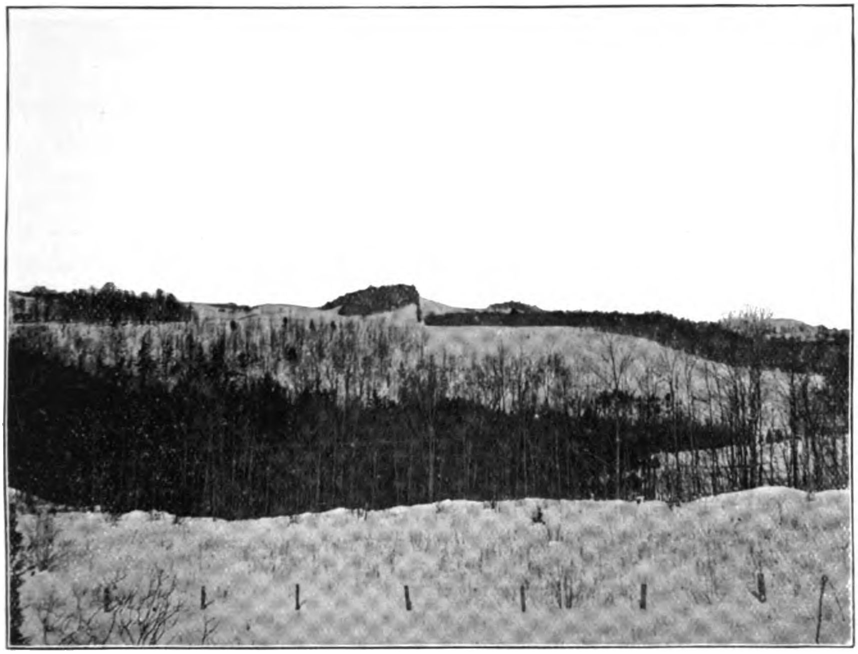


FIGURE 1.—VIEW OF EAST END OF ROCK GORGE

View was taken looking north where gorge enters Butternut valley, and shows delta accumulations capped by drumlins on far side of valley

FIGURE 2.—VIEW LOOKING NORTH ACROSS JAMESVILLE GORGE

Showing end of large terrace (left central part of view), which is on south side, and the faces of three terraces on the north side of the gorge

ROCK AND JAMESVILLE GORGES

seen to originate along these veins where they are exposed to the air by the removal of the vein matter. After the calcite or aragonite is removed to some depth the rock itself is dissolved by the rain water which stands in the depression thus formed, and thus the fissure widens somewhat as it deepens. Some experiments made with a view to ascertaining the solubility of the rock in ordinary rain water showed that in two months' time a very slight but distinctly appreciable per cent of the rock had passed into solution.*

Locally and at varying distances below the surface the fissures are found to widen, their walls retreating until a small chamber is formed, and it is thought that the caves which are not uncommon in the Lower Helderberg limestone of this region have been mainly made in this manner. At considerable depths below the surface, as shown at the foot of the west wall of Jamesville lake, the work of waters percolating down through these fissures is evidenced by the redeposition of stalactitic material on the walls of the fissure and on the roof of overhanging parts of its wall where it expands into a room.

KETTLE-FORM DEPRESSIONS

Jamesville lake is situated in a large, symmetrical, bowl-like depression about 400 feet wide and 500 feet long. It is 160 feet down to the lake surface, and the water itself is about 60 feet in depth. Perpendicular walls enclose the lake on three sides, the east side being open. They sweep around the lake in a curve of remarkable regularity and beauty from the southeast around the south, west, and north to the northeast side of the lake. The bottom of this natural bowl is occupied by a sheet of water of regular, broadly elliptical outline. While this is the most striking natural feature of this region, it is not the only one of its kind. The depression in which Jamesville lake lies is in fact only one of a number of similar kettles which are scattered all about this interesting neighborhood, and which apparently are to be distinguished from the Jamesville lake depression chiefly in point of size.

Two hundred feet west of the wall enclosing Jamesville lake, for instance, is a notable depression, with rock walls rising 75 to 100 feet above its lowest point, on the south, west, and north sides. The east side opens toward Jamesville lake. Again, not more than 100 feet north of the wall enclosing Jamesville lake on the north side, we come upon the edge of another depression, which consists really of two pit-like excavations lying so close together that they partially merge into one another. The larger one, to the southwest, is about 130 feet deep and 175 feet across. The

*The quantitative measurements were kindly undertaken by Professor E. N. Pattee, of the Department of Chemistry, Syracuse University.

smaller one is of lesser diameter and about 100 feet deep. They are separated by a ridge which rises like a partition about 50 feet above the bottom of the deeper hole. Farther to the north are a considerable number of other similar depressions of all sizes, from very small ones up to those which are nearly as large as those just described. To the southeast of the lake also are two depressions of considerable size, as shown upon the accompanying map.

These peculiar depressions are all excavated in Lower Helderberg limestone, though the top of enclosing wall is, in the case of the more westerly depressions, capped by harder layers of Oriskany sandstone and Corniferous limestone. A noteworthy feature of these depressions is the fact that they lie in the path of one or other of the well marked channels which traverse this region in a general east-and-west direction.

CHANNELS

Although Jamesville gorge proper begins only 200 or 300 feet west of the lake, plain traces of an old watercourse (see plate 12, numerals 1, 2, 3, 4) can be followed westward for a mile or more, and less plainly nearly to Onondaga valley. The contrast between the shallow and weakly differentiated courses to the west and the deep gorges east of Jamesville lake is striking and is characteristic of the other channels as well. The reason for this is not entirely clear, but it seems to be related to the character of the rock formation which dips gently to the west, so that in the region of the deep channels we have softer (Lower Helderberg) rocks capped by harder (Oriskany-Corniferous) beds, while to the west, where the channels are shallow, the only rocks exposed are hard ones.

The kettle-like depressions described lie in the eastern part of the region—that is, in the region of the deeper channels. They lie with one or two exceptions in the course of these channels. Their upstream or western side is in all the larger ones a high, steep wall of rock. The downstream side is low, the enclosing wall being removed on this side down nearly to a level with the bottom of the depression. The largest depressions are as a rule found in the course of the largest channel. This is true of the Jamesville lake depression and its gorge.

TERRACES

Several of the channels show more or less well developed terraces along their sides, but this feature is best studied in the Jamesville gorge. To the west of Jamesville lake, where the channel is broad and shallow, the terraces are correspondingly low and broad. From the lake eastward down the gorge proper the terraces are very strikingly developed. They are sharply outlined, high, particularly at the eastern end, and line the gorge from one end to the other. As in Rock gorge, they are cut in rock except at the eastern end, at the place of debouchment into the main valley, where they are cut in the sides of a clastic, delta-like deposit of adjacent material. There are here three principal terraces, which are themselves traversed by subordinate terraces.

The evidence here of active and extensive water work leaves little to be desired. The large quantities of water which at one time must have been here to have created channels and terraces on so large a scale as those we find would have produced a river of considerable size, though apparently much smaller than the present Niagara. The estimation of its volume is, however, a matter of considerable difficulty.

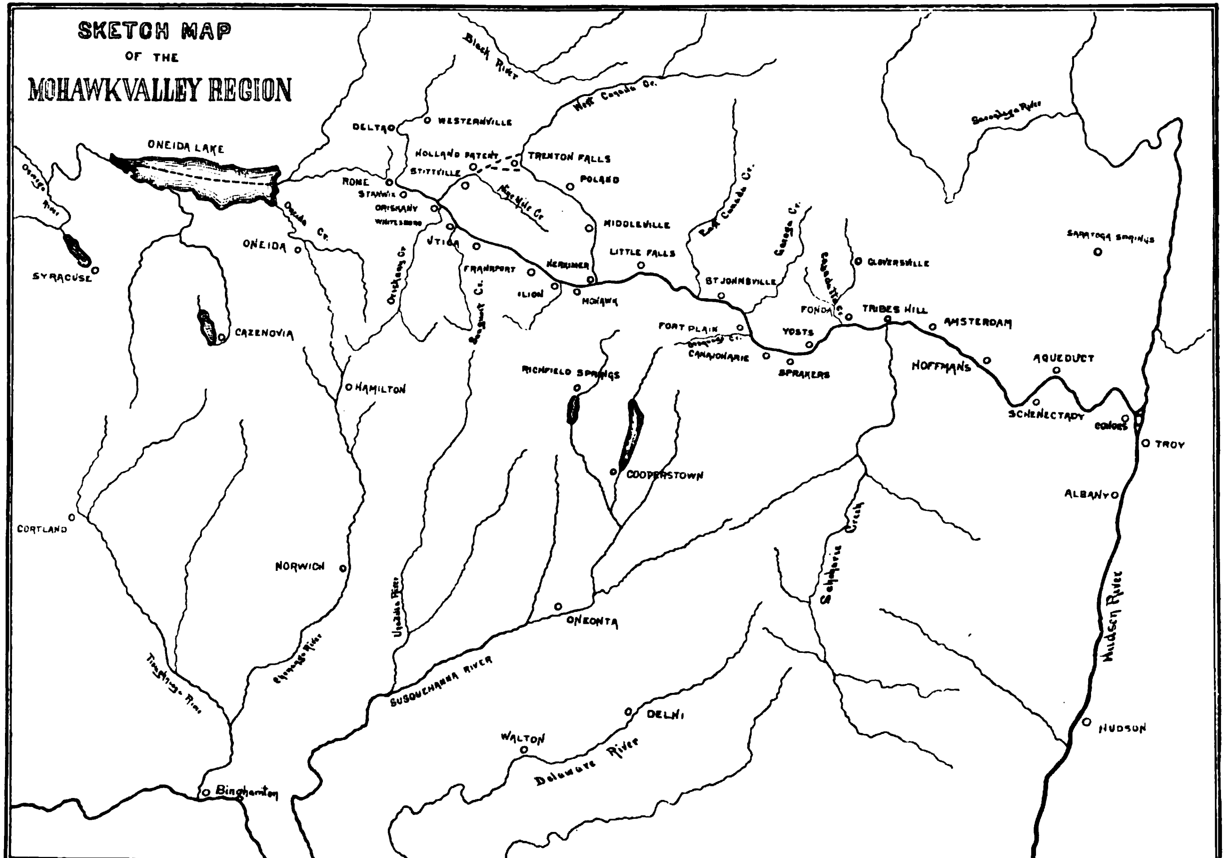
Summary and Conclusions

The origin of the fissures, caves, and channels which occur in the vicinity of Jamesville lake seems to be sufficiently well accounted for without a more detailed study. The kettle-like depressions which dot the region are more difficult of explanation. In speaking of them I have refrained from using the term sinkhole, although the term suggested itself at the outset on account of the strong resemblance of many of these depressions to the sinkholes of the limestone cave district of Kentucky; yet others do not resemble them. For example, several of the largest depressions hold or have recently held standing water, and do not seem, therefore, to lead into underground fissures or caverns. Again, in the northeastern part of the field depressions occur similar to those described, but in glacial clay, while side by side with them are those excavated in Helderberg limestone. In attempting to account for these kettles it is important to recall that they lie in the path of postglacial rivers of large volume; that the waters were moving from west to east, as shown by the delta-like accumulations; that the depressions occur in a region where hard and resistant rocks cap thick beds of soft and friable rocks, the strata tilting slightly upstream; also that the west (upstream) bank of the depression is usually steep and high and the east bank cut away. In short, the conditions are favorable for the formation of waterfalls and indicate their former presence, the depressions occurring in nearly every case at what might have been the foot of a waterfall. In other words, if we could today turn a good sized river across this plateau and through these channels there would be a waterfall formed at the west side of nearly all of the depressions.

The cave theory for the formation of these depressions has been referred to above. The fissures and caves which occur all through these rocks show that the dissolving power of the percolating waters has been considerable. The network of perpendicular and cross fissures have in places cut blocks of the rock entirely loose, so that they tilt when one steps upon them. The fissures, with their cave-like expansions, would in this and other ways undoubtedly assist materially in hastening the removal of the rock by running waters. It does not seem probable, however, for a number of reasons, that this is to be considered the chief or even a very prominent factor in comparison with the work of running waters. Thus the outlines of the depressions are too regular and their form too symmetrical for them to have been cave chambers, at least unless they have subsequently been much modified by other agencies. There are some two dozen of the depressions lying in the abandoned watercourses of this region, but outside of these watercourses the surface of the country all about is free from them. In the whole region where the depressions are so abundant only one or two caves are known and these are smaller than the great majority of the kettles and of very different form; while on the other hand, in other parts of the county, where caves of larger size are reported, sinkholes or kettle-like depressions are not known.

The formation of gorges like the Jamesville gorge and Rock gorge, the carrying of such large amounts of fragmental material as are found at the east end of these gorges and the carving of these into terraces which rise 50 to 60 feet above the gorge bottom could certainly not be ascribed to cave streams. A short distance east of Jamesville lake, Oriskany sandstone and the Corniferous limestone are not found in place, as explained above, and yet we find blocks or boulders of these rocks 3 and 4 feet long which have been transported half way down the gorge. These facts point also to powerful water action. The conditions found in Rock gorge confirm our conclusions as to the former presence of large and powerful erosive water currents. Our conclusion is, therefore, that the kettle-like depressions at and about Jamesville lake were formed, like the terraced channels in which they lie, chiefly through the action of postglacial streams, aided in some degree by percolating waters, which produced a network of fissures and cave-like openings in the rocks and thus rendered them a more ready prey to the action of eroding streams. If this diagnosis shall prove to be a correct one, the term "pothole lake" would perhaps not be inappropriate.

It is not intended to have it implied by what was said in the beginning that all the small, "round" lakes of the state are necessarily of the same origin as Jamesville lake. I am not sufficiently well acquainted with the class to be able to say to what extent this may be the case. I am, however, quite sure from what I have seen that Jamesville lake is not the only one of its kind in this part of New York.



MAP OF THE MOHAWK VALLEY REGION

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 9, PP. 183-210, PL. 15 FEBRUARY 19, 1898

TOPOGRAPHY AND GLACIAL DEPOSITS OF MOHAWK VALLEY

BY ALBERT PERRY BRIGHAM

(*Read before the Society December 28, 1897*)

CONTENTS

Present Topography

The Mohawk river, having its sources among the highlands of Lewis and Oneida counties, pursues a course of 130 miles to the Hudson. The direction is southerly 20 miles to Rome, then south of east to the discharge at Cohoes and Waterford. The altitudes, which do not depart widely from the present floodplain of the river, are, as given by Macfarlane for the New York Central railway, as follows:

Rome	445	Fort Plain	305
Oriskany	423	Palatine Bridge	304
Whitestown	415	Sprakers	301
Utica	410	Yosts	300
Frankfort	402	Fonda	299
Ilion	400	Tribes Hill	305
Herkimer	398	Amsterdam	279
Little Falls	376	Cranes Village	270
East Creek	334	Hoffmans	266
Saint Johnsville	319	Schenectady	246

The river level at Aqueduct, 4 miles below Schenectady, is 205 feet, and at Cohoes, above the falls, 130 feet; below, 70 feet. The Nine Mile, West and East Canada, and Garoga creeks, are the more important tributaries from the north, while the Oriskany, Sauquoit, and Schoharie enter from the south. The immediate valley is narrow and steep-sided to Delta, six miles above Rome, where it enters the Iroquois basin. This basin contracts to a river valley eastward from Rome, but continues broad and open toward Little Falls, with a concavity of bounding slopes which suggests powerful glacial erosion. At Little Falls the well known gorge continues for about two miles, followed by a fairly open valley to Schenectady, except at the Noses and Hoffmans. Near Schenectady the valley widens as it enters the great Champlain-Hudson lowland, and the river zigzags by a shallow and immature channel to the Hudson.

The importance of the valley as a topographic feature is not appreciated until one stands on some commanding point of view on the uplands. We then discover a great trench 1,500 feet deep and from 12 to 20 miles wide. Such points of view are Starr hill, in northern Oneida county—altitude, 1,793 feet—and Tassel hill, near the south border of the same county—altitude, 1,948 feet. Northeast of Utica, within 6 miles of the valley, several hilltops rise to 1,500 and 1,600 feet. The foothills of the Adirondacks come down close to Little Falls, while the Utica shale area about Johnstown and Gloversville is reduced to levels of 600 to 800 feet. On the south the Catskills grade down to the plateau level of central New York, lying south of the Helderberg escarpment, with common altitudes of 1,500 to 1,700 feet. An exceptional slope appears at Rotterdam, where an altitude of 1,385 feet is attained within a mile and a quarter of the valley bottom. One thousand to 1,400 feet are common heights for the southern parts of the Fonda and Amsterdam atlas sheets. Geographic reasons for town sites abound. Six cities lie upon the short course of the stream, and more than that number of large and important towns. A ford, waterfall, or open ground at the mouth of a tributary is the usual physiographic factor in the history.

Preglacial Drainage

CRETACEOUS PENEPLAIN

Studies of the region are not sufficiently matured for confident assertion. Besides large tracts to north and south, the Herkimer-Sprakers section of the immediate valley is yet unmapped, but considerations have developed which seem worthy of statement. Until the district is mapped, it is reasonable to assume from much general observation that the plateau south of the valley, extending into Pennsylvania, is a part of the uplifted and dissected peneplain described by Davis and others for the eastern and southern Atlantic region. The structure is the same as in northern Pennsylvania, "a peneplain on which successive formations crop out, one shingled on the next as we cross the country."*

These formations originally extended much farther to the north, carrying the peneplain to an undetermined distance in that direction. An outlier of Potsdam, Calciferous, and Trenton is now found at Wellstown, 12 miles from the body of these formations, at Northville. The Hamilton rocks would overreach much of the present course of the river if carried northward for an equal distance from their present outcrop, and the same may be said with stronger emphasis for the Helderberg series of limestones. Into the northern edge of the great peneplain, the Mohawk valley was cut by prolonged erosion.

COURSE OF ADJUSTMENT

It is assumed that the ancient constructional streams led from the Adirondacks south and southwestward across New York into the Penn-

*W. M. Davis: The geological dates of origin of certain topographic forms on the Atlantic slope of the United States. Bull. Geol. Soc. Am., vol. 2, p. 560.

sylvania region. It is also assumed that the Hudson valley is a product of Tertiary erosion,* and that there was a Laurentian valley before the elevation of the Cretaceous peneplain. Westgate points out that the Laurentian drainage is of the subsequent order, and that the adjustment by which waters originally flowing southward were led to course along the strike of the Paleozoic beds, may have taken place in the Permian-Cretaceous interval.† It is assumed in this paper that the southern Adirondack streams and Susquehanna headwaters may be truly considered as descended, without serious modification of location or direction, from streams consequent on Paleozoic topography.‡ It is to be also remembered that the Mohawk valley is near and roughly parallel to the pre-Cambrian-Paleozoic contact. This contact line is irregular, both on account of Adirondack folding and the Mohawk valley faults. Overlying the relatively thin Calciferous and Trenton, and less subject to the irregularity produced by faulting, is a thick but yielding mass of Utica and Hudson River shales. Given therefore the growing Hudson valley and a steep upland on the west, with the tough Adirondack masses on the one hand and the hard Helderberg and Hamilton terranes of eastern New York on the other, it was to be expected that a valley would be formed with headward cutting westward along the Utica-Hudson strike. But for the irregularities above noted the river would almost surely have kept the north boundary line of the Paleozoic, as is conspicuously the case with Black river, which flows for 50 miles with slight divergence from this line. Dr Bell, of the Canadian Geological Survey, has made some interesting observations as to the effect of glaciation on such a contact.§ Apparently the Mohawk headed west as far as Little Falls. The Mohawk may therefore be considered a monoclinal valley, though structural irregularities and inequalities of glacial erosion have somewhat disguised this chief character. In harmony with this view, Dana many years ago noted that the southern plateau was higher than that lying to the north.|| He, however, defined the valley as "geoclinal." In similar fashion, as it seems to the writer, a subsequent valley was formed from the ancient Laurentian valley, heading to Little Falls. West of Rome it may have passed along the axis of Oneida lake or farther south. In any case the form of the Iroquois basin on the east appears to be due to

* W. M. Davis: The Catskill delta in the Postglacial Hudson estuary. Proc. Bost. Soc. Nat. Hist., November, 1891, p. 319.

† Lewis G. Westgate: The geographic development of the eastern part of the Mississippi drainage system. Am. Geologist, April, 1893, p. 245.

‡ On the probable character of such topography see Chamberlin and Salisbury: Driftless area of the upper Mississippi valley. Sixth Ann. Rep. U. S. Geol. Survey, p. 224.

§ Robert Bell: On glacial phenomena in Canada. Bull. Geol. Soc. Am., vol. 1, p, 296.

|| J. D. Dana: On the existence of a Mohawk Valley glacier in the Glacial epoch. Am. Jour. Sci., 2d series, vol. xxxv, 1863, pp. 243–249.

the narrowing and thinning eastward of the Medina, Clinton, Niagara, and Salina formations.

The Adirondack waters on the south and west were thus diverted by the Mohawk, the Black, and what we may call a "Rome" river. The Susquehanna was robbed of much of its territory, and its beheaded affluents now contest the ground in a losing struggle with the southern tributaries of the Mohawk, for in steep gradients and proximity to tidal water the Mohawk has a large advantage over the upper Susquehanna. Some headwaters of the Oriskany and Sauquoit seem clearly to have been pirated away from their former connection southward. This conquest of territory finds an apt parallel in the landward migration of the Appalachian divide and the beheading of the rivers of Kentucky and Tennessee by the "Appalachian" river.*

COL AT LITTLE FALLS

The existence of a water parting at this point is set forth briefly, but with much confidence, by Chamberlin. His language is as follows:

> "It was here, as I think, that a preglacial watershed parted streams that, on the one hand, flowed eastward to the Hudson, and, on the other, westward to the Ontario basin. Neither glacial erosion nor accumulation has been here sufficient to obliterate the main features of the preglacial topography. The watershed may be quite confidently and exactly located near Little Falls. The cutting of the upper and broader rock-gorge of the Mohawk at that point appears to have been the work of the earlier Glacial epoch and of interglacial drainage. It certainly antedated the close of the Glacial period, for the ice passed through it, rounding and scoring its ledges, but appears to have in no great degree modified its form or enlarged its capacity."†

The writer believes that the above conclusion is fully sustained by further studies. The Little Falls station of the New York Central railroad is not far below the top of the gneiss at that point, and the altitude is 376 feet. Thence the river descends for about a mile and a half to an altitude of 322 feet at the fault. Restoring at least 118 feet for postglacial gorge-cutting in the gneiss at that point, we find a barrier having an altitude of 440 feet. We must add to this an unknown amount for glacial or other erosion during the long progress of the Glacial period. As will appear later, the Little Falls fault determined the position of the divide by interposing the most resistant rock-mass between Hudson valley and lake Ontario. In addition, we have the important fact that the rock bottom of the valley descends, though not uniformly, from Little Falls to

*C. W. Hayes: Southern Appalachians. Nat. Geog. Monographs, p. 322. Hayes and Campbell: Geomorphology of the southern Appalachians. Nat. Geog. Mag., vol. vi, p. 103.

†T. C. Chamberlin: Preliminary paper on the Terminal moraine of the second Glacial epoch. 3d Am. Rep. U. S. Geol. Survey, p. 362.

the region of lake Ontario. The arrangement of tributary streams to the west is also more normal to a westward than an eastward flowing stream. An inspection of the course of the Sauquoit, Oriskany, and Nine Mile creeks will support this suggestion, particularly if the hint given later as to the former course of the West Canada creek proves tenable. The upper Mohawk for several miles above Rome probably also took a more westerly course. Decisive weight cannot be given to the arrangement of streams in this case, however, since a normal dendritic arrangement is hardly to be expected if a subsequent Rome river diverted its tributaries from consequent courses.

ROCK TOPOGRAPHY WEST OF LITTLE FALLS

Information concerning wells between Little Falls and Oneida, as above indicated, demonstrates descent of the rock floor westward, and also seems to prove the existence of a rock basin between Utica and Little Falls. The records at hand are given below.*

At Herkimer a well was put down by the West Canada creek, perhaps a half mile from the main valley, disclosing the following succession:

	Feet.
Black loam	5
Coarse gravel	20
Lacustrine clay	100
(40 feet north of well clay is only 30 feet thick.)	
Fine gravel	22
Sandstone boulder	7½
Gravel (to rock)	2½
	157

At Mohawk, on the south edge of the valley, a well at the knitting mill, by the canal, shows this section—rock not being reached:

	Feet.
Sandy loam	18
Blue clay, no pebbles	20
Thin beds of gravel and sand, including much quicksand	106
	144

At Ilion we have the following from the well at the Remington Standard Typewriter works. The mouth of the well is at 405 feet above tide, and the location on the south edge of the floodplain. The drift is 195 feet in thickness, mainly of fine gravel. Two beds of quicksand, each

*The writer is indebted for well records to Dr E. G. Kern, of Herkimer; Messrs B. B. Van Deusen and A. N. Russell, of Ilion; E. A. Rowland and Dr W. L. Kingsley, of Rome, and P. H. Foley, of Utica. The last has drilled extensively in central New York.

8 to 10 feet, were encountered, but their position is not given. There is no clay in the section, though clay is common south of the canal, in the town, adjacent to a tributary stream. Thus a well at the Armory is 72 feet deep and shows—

	Feet.
Sandy loam and gravel	11
Blue clay, about	60

The clay is reported as fine, with pebbles rare, but, if present, believed to be waterworn. Another well, a quarter of a mile south of the canal and 90 feet deep, shows alternating clay, quicksand, and some layers of coarse sand or fine gravel.

In the eastern part of Frankfort village, 20 rods south of the canal, the well of Mr George Tapling affords this section:

	Feet.
Loam and gravel	16
Fine blue clay, no sand or pebbles	48
Quicksand to clay	3
	69

At Harbor, 4 miles east of Utica, rock appears at about 45 feet. In Utica several wells are well spaced across the floodplain. The first is by the river, on the south edge of the floodplain, with depth to rock, 63 feet. The second is at the tollgate, with rock at 58 feet. The third is between the tollgate and Deerfield Corners, with rock at 42 feet. At Deerfield Corners rock is found at 33 feet and thence at less depths to the south side. Rock continues at about these depths to Stanwix, near Rome, and then descends to the west. None of the wells from Stanwix eastward, sunk midway of the valley, show fine, smooth clay without pebbles, but the usual material is "clay hardpan." As a rule, the stones are coarser toward the bottom. One 4½ feet in diameter is noted, while those of from one to one and a half feet in diameter are said to be very common. These statements are on information of Mr Foley.

A well was bored for gas by the Rome Factory and Building Company near the Central railway. The drift section is appended:

	Feet.	Inches.
"Top dressing"	3	7
Sand	17	
Clay	20	
Quicksand	25	
Clay	20	
Hardpan to rock	31	
	116	7

Several other gas wells at Rome show the following drift sections, in all cases to the rock:

Second Rome Well.

	Feet.
Artificial filling	16
Clay	14
Coarse gravel	87
Stones and hardpan	8
	125

Fourth Rome Well.

	Feet.
"Sandy loam"	75
Clay	39
Hardpan	8
	122

Third Rome Well.

"Sandy loam"	70
Clay	7
Hardpan	6
	83

Fifth Rome Well.

"Sandy loam"	50
Hardpan	8
	58

The "sandy loam" reported is probably a fine silt-like sand. A general section shows hardpan, probably boulder-clay, overlain by fine clays, and these in turn by fine sands, with one thick intercalation of gravel. At the Rome cemetery rock was found at 70 feet. At Saint Marys cemetery, northwest of Rome, a boring of 166 feet did not reach rock. The material was nearly all sand and gravel. At the Silver Plating works, Oneida, the depth is (probably) 170 feet to rock. At the Warner Electric and Power plant, Oneida, a depth of 117 feet was attained without striking rock. Nearly all the material was quicksand. A slight layer of gravel was found at 50 feet, another at 100 feet, and 3 to 4 feet of coarse gravel with cobblestones were penetrated at the bottom. About Durhamville 40 to 60 feet of fine clays are common, overlain by 15 to 18 feet of sandy loam and glass sand. At Sylvan beach, Oneida lake, 150 feet were traversed without rock. At a depth of 22 feet 60 to 70 feet of clay were encountered, underlain by gravel. The altitudes of the rock bottom at the several points are approximately, as deduced from the above data, as follows:

	Feet.
Little Falls	376
Herkimer	241
Mohawk	252
Ilion	210
Frankfort	329
Harbor	358
Utica	347
Rome	320
Sylvan Beach	220

It should be remembered that in the Herkimer-Ilion section and the Rome-Oneida section these figures may not represent maximum depths in the middle of the valley.

It thus appears that between Harbor and Little Falls a true rock basin exists, 18 miles long and having an ascertained depth of nearly 150 feet below its lowest or western rim. It is excavated in soft Utica shales, and if, as appears, the work was done by the eastward-moving glacier of the upper Mohawk valley, it affords a close and interesting parallel to the rock basin part of the Finger Lake basins of western New York.*

PREGLACIAL COURSE OF THE WEST CANADA CREEK

Only a tentative statement is here offered. Reference to the map (page 183) shows that West Canada creek turns abruptly from the southwest to the southeast about Trenton Falls and enters the Mohawk at Herkimer. It is held as possible that before Glacial time its course may have continued to the southwest, past Holland Patent, along the Nine Mile Creek valley to the Mohawk, near Oriskany. The evidences are a broad open valley, adequate to the Ohio or Susquehanna, at Holland Patent and Stittville, now occupied by a minor stream; the more normal arrangement of drainage thus postulated; massive barriers of glacial debris north and east of Holland Patent; superior altitude of West Canada valley bottom below Trenton Falls as compared with Holland Patent; a very level stretch of some five miles of the West Canada creek about Poland, and the constriction of the valley about Middleville.

The supposition is that morainic obstruction blocked the old channel and sent the creek across a col not far from Middleville.

DIVERSION OF HEADWATERS OF "ROME" RIVER

The explanation is clear. Glacial erosion at Little Falls and the later, eastward, eroding flow of glacial waters would in considerable measure cut down the rocky col, while an immense mass of glacial debris was discharged into the valley, aggrading its bottom from Rome eastward. This discharge was mainly from two sources, the upper Mohawk, debouching above Rome, and West Canada creek, which, whatever its early course was, certainty formed a great outlet by Holland Patent during the recession of the glacier and while its present lower course was filled with glacial ice. This is shown by the extensive deposits of gravel and sand about Remsen, Trenton Falls, Holland Patent, and for a few miles eastward, while below Newport massive tills clog the valley to

* See A. P. Brigham: Finger lakes of New York. Bull. Am. Geog. Soc., vol. xxv, no. 2, 1893; also R. S. Tarr: Lake Cayuga a rock basin. Bull. Geol. Soc. Am., vol. 5, 1893, p. 339.

Herkimer. Once discharged into the Mohawk valley at Rome and Oriskany, the gravels were spread eastward by the great currents flowing out by the Mohawk valley.

MATURING OF THE LOWER MOHAWK VALLEY

As described by Vanuxem, and in greater detail by Darton,* a series of faults crosses the river between Little Falls and Hoffmans. The uplift in each case is on the west, and to a greater or less degree the gneiss, the Calciferous, and Trenton are brought up within the reach of the valley-making agencies. It would be difficult to find a more instructive example of the effect of hard rocks in retarding the maturing of a valley. But for the faults the lower Mohawk should be as broad and well developed as the upper valley, unless indeed the western Mohawk glacier was more effective in excavation.

Three of the dislocations have especially influenced the topography. At Hoffmans no gneiss exposed is to be seen, but the Calciferous and Trenton appear for several miles, with noteworthy bluffs of Calciferous, and the valley bottom is but a scant fourth of a mile in width. The valley is still more immature at the Noses, both because it is farther upstream and because a greater thickness of hard rocks is encountered. The whole thickness of the Calciferous is exposed, and of the gneiss, according to Darton, 40 feet on the south side and 70 feet on the north. Strong bluffs run for several miles, attaining a height of 500 feet toward the fault, and facing the river with many slopes of 40 to 60 degrees, rising in places to the vertical. The cliff runs northward for some miles, and to the east the valley becomes at once broad and well matured. The topographic effects at Little Falls are sufficiently well known, and in general it may be said that but for the series of faults the Hudson's advantage should have anciently given it the country as far west as Syracuse. Part of the area which it lost for structural reasons it has gained by means of glaciation. It should be added that from Little Falls to Hoffmans the river flows approximately on a rock bottom. The hard rock barriers have not been breached to any extent below the level of the stream, though it is possible that minor rock basins lie between them. Rock is exposed in the bed of the river at the state dam, 5 miles below Little Falls; also on the edge of the floodplain at Indian Castle. At Saint Johnsville rock lies at a depth of 14 feet by the edge of the river. From Saint Johnsville to Palatine Bridge on the north side drift is scanty, exposures of rock being frequent and often continuous along the lower slopes. At Canajoharie and the Noses rock appears at the edge of the

* N. H. Darton: A preliminary description of the faulted region of Herkimer, Fulton, Montgomery, and Saratoga counties. State Museum Report, vol. 2, no. 48, 1896.

stream on either bank; also on the north side at Tribes Hill and Amsterdam. Accepting the current view, which dates the faults back to the Appalachian revolution, no sign of them probably appeared upon the Cretaceous peneplain, for only by later erosion have the hard rocks been encountered.

Glacial Movements

The facts are not so fully in hand as would be desired. The only constructive account is by Chamberlin, in the terminal moraine report already cited.* He briefly describes the deposits of the western Mohawk glacier, gives a number of observations of striæ, including references to Vanuxem and Dana, and says:

> "I hesitate, at this stage of the inquiry, to encourage any confident opinion in regard to the exact history of glacial movements in the Mohawk valley, further than the general presumption that massive currents having their ulterior channels in the Champlain valley on the one hand and the Saint Lawrence on the other, swept around the Adirondacks and entered the Mohawk valley at either extremity, while a feebler current, at the height of glaciation, probably passed over the Adirondacks and gave to the whole a southerly trend. It should not be overlooked that this valley lies sufficiently back from the average limit of glaciation to afford the presumption that the earlier and later movements may have been quite different."

Gilbert, from later observations, appears to be in accord with Chamberlin's view.† The writer's studies have not been directed especially to this point, but a few pertinent observations have been incidentally made. The linear east-and-west arrangement of topographic forms noted by Chamberlin is strongly confirmed by field observation and by the recently issued Amsterdam and Fonda atlas sheets. Some observations of striæ were made. On the south side, between Saint Johnsville and Fort Plain, on a surface of Utica shale inclined 12 to 21 degrees southeast, are well defined groovings running north 53° to 60° west, and a minor set north 75° west. The direction of the main set coincides with that of the valley at this point. At the quarry of A. E. and D. C. Shafer, Canajoharie, on a flat surface of limestone, the direction is north 75° west. At Palatine Bridge, on a cellar bottom at the residence of S. L. Frey, the direction is north 73° west. All readings are magnetic. At Amsterdam, on the north side, above East Main street, a case was found which appears to be demonstrative of westward flow. The accompanying diagram perhaps needs little explanation. The striæ run westward on a flat limestone surface. A flake somewhat larger than one's hand

* Pages 561–565.

† Letter to the writer, February, 1897.

and from three-eighths to half an inch thick has been plucked, leaving a ragged rim to the east, north, and south, while the westward edge of

FIGURE 1.—*Striated Surface of Limestone at Amsterdam.*

The diagram is about one-half natural size. The arrow indicates the westward direction of striæ.

the depression is, with one slight exception, well subdued. The inclosed space is as perfectly polished as the surrounding area, and on the west the general surface drops by a narrow bevel to a slightly lower plane.

Drift Deposits

PREVIOUS INVESTIGATIONS

Considering that the Mohawk valley has long been known to geologists as an important channel, published observations concerning it are surprisingly few. Vanuxem alludes to a "determinate order of alluvial deposits," namely, blue clay, covered with sand and sometimes with rolled stones. He mentions a few of the large bodies of drift.* Dana, in his paper on the Mohawk Valley glacier, thus refers to the character and importance of the terraces:

"The subject of river terraces, or stratified post-Tertiary deposits, on the Mohawk and its tributaries is also one of great interest in this connection and merits a thorough examination. The deposits have some relation to the drift, as they belong to the epoch immediately following—the Champlain epoch—and consist in part, at least, of material that had been transported by the ice. They are of unusual extent on the East and West Canada creeks and other northern tributaries of the Mohawk."

Chamberlin, as already noted, gives a general description of the drift shoulders between Utica and Little Falls, and Merrill alludes to them in

* L. Vanuxem: Geology of the Third District, p. 212.

discussing the clays and sands of the Hudson valley,* and cites the views of Gilbert and Spencer as to their nature.

Taylor gives a short account of these accumulations and notes that they are deltas rather than true river terraces.†

The drift of the Mohawk, as might be expected from difference of position and greater complexity of relations, contrasts with the drift of the Chenango valley. The former has massive tills, few kames or kame terraces, and affords lacustrine clays above the level of the floodplain. The latter has numerous masses of kame with frontal terraces, many kame terraces, no massive tills, and all its lacustrine clays are buried beneath the floodplain.‡

The subsidence of glacial waters from the Warren to the Iroquois plane is as yet imperfectly understood. Gilbert refers to a baselevel higher than the Iroquois plane, "probably determined by an ice-dam in the lower Mohawk valley."§ Fairchild has made known one important stage in this subsidence by his discovery of the Geneva beach, which he has described in detail and of which he gives this summarized account:

> "A well defined beach lying at an elevation of about 700 feet has been traced for 30 miles along the western side of Seneca Lake valley and westward to Shortsville, while evidences of the same static water have been noted farther west. It is supposed that these phenomena belong to a long pause in the irregular fall of the Laurentian glacial waters from the Warren level to the Iroquois level." ||

It is believed that the studies which follow throw light upon one additional stage of this subsidence. The bodies of drift lying between Westerville and Little Falls will be taken up in order.

UPPER MOHAWK VALLEY

Upper Mohawk delta.—This is the deposit made by the upper Mohawk at its entrance into the Iroquois basin. Only the southern portion, about Rome, has been mapped, and the study has been but partial. The slightly generalized map (plate 15, page 183) shows the principal relations at the head of the delta. At Westernville, 8 miles northward from Rome, the river leaves its deep trench in the northern plateau and makes a broad swing to the west past the village of Delta, returns to the east, bends sharply to the south, and passes through a gorge in the shales 80 feet

* F. J. H. Merrill: On the postglacial history of the Hudson River valley. Am. Jour. Sci., vol. xli, 1891, p. 460.

† See communications by F. B. Taylor and Warren Upham in the American Geologist, May and June, 1892.

‡ A. P. Brigham: Glacial flood deposits in Chenango valley. Bull. Geol. Soc. Am., vol. 8.

§ G. K. Gilbert: Old tracks of Erian drainage in western New York. Bull. Geol. Soc. Am., vol. 8, p. 286.

|| H. L. Fairchild: Glacial geology of western New York. Geological Magazine, December, 1897, pp. 529-537. See also Bull. Geol. Soc. Am., vol. 8, p. 271.

deep and locally known as the "Palisades." Westernville lies upon a terrace 36 feet above the river and about 575 feet above the sea. This terrace continues southward toward the Palisades, but less simply than the figure suggests. On the west the terrace level swings, like the river, past Delta village around to the Palisades, capping a steep eroded bluff of sand and gravel 75 feet high and bordering a tract of slightly rolling drift to the west and south. The bowl-shaped depression is about 2 miles in diameter, and may have been kept open by stagnant ice, though its borders have been rimmed out by the broad meander of the stream. There can be little doubt that the preglacial river flowed past the site of Delta village into the "Rome" river; that the passage was blocked by a widespreading apron of drift and the river forced to cut a new passage at the Palisades, maintaining for a time a lake in the bowl to the north. The rock surface at the top of the Palisades bluff on the east was well swept by the stream before the gorge was begun.

Rome-Floyd stagnant ice area.—Extending from near Rome and the Palisades east and southeast to Floyd is a broad and broken terrace which seems to have been formed in the presence of lacustrine waters and of stagnant ice. It is 4 to 5 miles long and varies in width from 1 to 2½ miles. Its higher surfaces rise from 520 feet above sea on the riverward side to 600 feet, where it abuts upon the hill slope at the north. Its margin is much broken with some isolated tabular masses, and resembles the kame terrace. Its top surfaces as they appear on the atlas sheet, drawn to the 20-foot contour line, are much too uniform. The sections all show sand and gravel, with inclined and discordant stratification.

Nine Mile Creek delta.—Here is one of the most interesting bodies of drift in the valley. This is not due to good structure sections, but to its relations and surface expression. There can be no doubt that the aqueo-glacial discharge from the basin of West Canada creek was chiefly at this point. The head of the delta is approximately at Holland Patent, at an altitude of 600 feet. Thence the delta extends 5½ miles to the Mohawk floodplain, where its altitude is 520 feet and its height above the flood-plain 100 feet. It is narrow at Holland Patent, but widens symmetrically to 3 miles at its frontal edge, or if, as is probable, a massive bench of drift to the southeast is genetically connected with it, the width should be put at 5 miles. Its surfaces are exceedingly smooth and the mass is beautifully dissected to the bottom. The materials are coarser toward the head, and at the front consist exclusively, so far as seen, of fine sand, which at two points is kept bare by the action of the wind. The drift mantles a floor of Trenton limestone and Utica shale, and is of no great thickness, except toward the front. To the south and east runs the very massive shelf of drift to which reference has been made. It is two miles long and half a mile wide. Its height is uniform with that of the rest of the delta, from which it has been cut off by a postglacial ravine. Like many of the drift banks of the valley, it has suffered erosion on its riverward side.

Oriskany-Whitestown sandplain.—This is a noteworthy accumulation stretching between the towns named on the southwest border of the valley. Its origin and relations are not clear. The main mass or "Oriskany bluffs" has an altitude of 540 feet. At Whitestown the altitude is 500 feet. On the valley side the slope is chiefly a product of erosion; on the west and southwest is a kame area, whose surfaces in part fall below and in part rise above the terrace, ranging between 480 and 600 feet. The mass lies at the mouth of the Oriskany creek, but both the surface expression and the internal structure appear to forbid the supposition that it is a delta related to that stream. Toward Oriskany an extensive opening at the base of the bluffs gives a section of 30 feet. At the bottom are 15 feet of very coarse, much indurated gravel, with a profusion of cobblestones and small boulders. Above the gravel a fine, sandy silt is exposed to a thickness of 15 feet. This silt is seen in fresh excavations along the way to Utica continuously for nearly a mile. About midway of the mass is a nearly complete section from the base to the top. At the base is an exposure of 30 feet of fine sand alternating with beds of very fine silt, which holds moisture and "cuts like cheese." Except at the top there is absolute freedom from gravelly material or even coarse sand. The beds incline slightly, but uniformly away from the valley. Above an unseen interval of 20 feet or more is a 45-foot section, showing 15 feet of tumultuous coarse and bouldery gravel at the top, and below alternating sand and gravel with some cross-bedding. Its general inclination, however, as well as that of the silts below, is from 1 to 3 degrees southwest. A generalized section for the whole deposit, therefore, gives us a great body of fine silts intercalated between two massive bodies of glacial gravels. At Whitestown the coarse gravels are absent so far as seen. There is a slightly pebbly layer at the top, underlain by nearly 70 feet of very fine sand. Alternating thin layers are seen of finer or at least more coherent material, and with such regularity as to suggest a seasonal variation in deposition. The slopes here show evidence of ice contact and the water currents seem to have come from the north side of the beds. This fact and the inclination of the beds in the Oriskany bluff suggest a connection with the Nine Mile Creek delta, whose precise nature is, however, in doubt. The Oriskany beds are 20 feet higher than the edge of the delta. But for this fact it would be reasonable to suppose that the delta deposits extended across the valley and have been breached by the river. Perhaps the two masses mark different stages of recession.

Frankfort-Ilion drift benches.—A noncommittal term is here used for aggregations which may in part have the nature of deltas. The valley about Utica is quite free from marginal drift. As indicated by Chamberlin, drift shoulders appear a few miles to the east, becoming strong about Frankfort and Ilion. Three miles west of Frankfort a section of 60 feet, obscured by slip at the base, displays 30 feet of horizontal beds of yellowish silt, with blue clayey layers above, still overlain by 10 feet of tough unstratified till containing many small scratched pebbles. Thence the surface rises by a concave curve to the steep upper hillside without any line of demarkation between the deeper drift of the valley and the thin mantle of the higher slopes. This is a common phase of the valley topography from this point to Little Falls. The valleyward edge presents an erosion escarpment gashed by numerous small ravines. Eastward the bench fades to a gentle slope, reappearing near Frankfort as a considerable feature. It is a mile and a half long and a mile wide, having an altitude of 480 feet on the river side and 540 to 560 feet at the base of the valley slope on the southwest. The surface is a gently sloping plane, rather stony. Toward the river, sections of 6 to 8 feet show sand, and in one case open gravel inclined toward the valley. Farther back coarse gravel with boulders is found, and under this sometimes fine clay. Structure and contours suggest the delta, but the stream from the southwest is local, and the drift mass lies wholly on one side of it. Possibly the mass is related to a yet unstudied channel passing south of Frankfort hill, which may have acted as a spillway before the main valley was open.*

A similar terrace lies on the west of Ilion, having the same altitude in front, but rising to 600 feet, a mile and a quarter south, in the valley of Steeles creek. Near the front a 16-foot excavation penetrated coarse gravel above and fine gravel below. Farther south, in a sand pit at the upper edge of the terrace, several feet of coarse gravel were found to be underlain by 25 feet of fine, horizontally bedded sand. At the 600-foot level farther south the section afforded by Mr Warner's well is—

	Feet.
Sand	10
Fine, blue clay; no pebbles	60
Gravel	1
	71

A small shoulder appears on the east side of the creek, from the Remington residence south toward the cemetery. Here a well was drilled to a

*See forthcoming Utica atlas sheet, a preliminary proof of which is in hand, through the courtesy of the U. S. Geological Survey.

depth of 80 or more feet, mainly in solid blue clay. The Ilion mass also has many characters of the delta, though the massive clays are anomalous in position, on this hypothesis.

On the north side, from Frankfort to Ilion, is a shoulder of moderate width, in which several sections show undisturbed sand and gravel below and 10 to 12 feet of till with scratched pebbles at the top. In one section a bedded layer lies midway in the till. At Coppernoll's sandbank, near Ilion station, fine waterlaid clay with scratched pebbles and thick overlying sands have been much disturbed and folded, thereby incorporating with the sands boulders of the clay with slickensides.

Ilion-Mohawk kames.—From Ilion station a belt of kames extends a mile or more eastward to, but not including, the Herkimer cemetery. On the south side massive kames rise above Ilion village on the east and extend to the eastern limit of Mohawk village, south of Herkimer. It is the only noteworthy illustration of these forms in the Mohawk valley. Altitudes of 580 feet above tide are attained. The sections are not altogether typical for kame, and we may have here an aggregate largely due to lacustrine deposition and subject to subsequent erosion. In some measure, however, the contours appear to be constructional. The dominant material, save at the base, is a fine yellowish sand, verging sometimes into loam or clay. The valley of a local stream in Mohawk divides the mass into two parts. A section by this stream gives 12 feet of very fine, black, horizontal, waterlaid beds of clay with scratched pebbles, overlain by nearly 50 feet of alternating, thin, horizontal beds of gravel and loamy sand. A section in the eastern part of Mohawk gives 50 feet, passing from good building sand at the base through loam and clay to fine yellow sand above. At the West Shore station, Mohawk, 6 feet of gravel are overlain by fine waterlaid clays with glaciated pebbles, and these in turn by the yellow sands. A few rods eastward by the railway the same clays rise 36 feet above the track, surmounted by 20 feet of the sands.

West Canada Creek delta.—This delta has a meager development. Its valley was apparently occupied by an active glacier to a late stage, as appears from the massive blue tills rising to a height of about 200 feet, constricting the valley for several miles. A short distance above Herkimer a sharp crested, crescentic moraine nearly blockades the valley. Much of the original delta must also have been swept away both by the river and its tributary. A gravel shoulder runs westward past the Warner Miller residence to the Herkimer cemetery. On the east a broad shoulder, with an uneven surface, swings around toward Little Falls. It consists of till to the north, thinly mantled with waterlaid material, but passes into clay and gravel in the main valley. Faintly inscribed on the top of this shoulder a series of water levels appears from the

Mohawk valley northward for a mile or more. These levels range from 490 feet to slightly above 600 feet. South of Herkimer, across the valley, lies the frontal portion of the delta. It may have been built at the front of an ice lobe pushing across the main valley, or may have been largely cut away by river erosion. At its north edge by the canal 10 feet of fine, black, tough, lacustrine clay are overlain by 15 feet of very coarse gravel. The apron terminates short of the south side of the valley, leaving a depression through which the West Shore railway passes. The gravels have been extensively excavated for ballast, and are rather fine and in beds inclining southward. Position, contours, and structure are demonstrative of their origin.

Deposits about Little Falls.—A massive shoulder of drift continues on the south side to a point near Little Falls, going east. The clays and fine sands give way to ordinary kame gravels and contours. At the northwest of Little Falls a very strong embankment of drift appears, consisting of till below and sands and gravels above. The mass is kame-like above the town, but a solid shoulder to the west, where its altitude is 808 feet above tide by the aneroid. The escarpment on the south border of the shoulder is steep and gashed by deep erosion gorges alternating with sharp spurs.

It will have been seen from the detailed account of beds between Utica and Little Falls that a generalized section of the marginal drift from the top downwards will stand as follows:

Till, overlying undisturbed beds of sand and gravel........	10–12 feet.
Fine to coarse sands and gravels...	A variable thickness.
Waterlaid, fine clays with glaciated pebbles...............	A few to 36 feet.

No till appears west of Utica and no fine clays, except below the valley bottom, though the sands and silts are very fine.

Discussion of levels and succession of events.—The altitudes of the several deposits thus far described fall into fair accord.

	Feet.
Head of Rome-Westernville delta, about......	575
Nine Mile Creek delta.......................	600 to 520
Oriskany-Whitestown terrace.................	540
Frankfort (delta)..........	560 to 480
Ilion (delta)...............................	600 to 480
West Canada Creek delta....................	600 to 490

These figures indicate a waterlevel at about 600 feet.* The lower limits of height represent offshore delta deposits. If the accordance of

* Professor Davis has called the attention of the writer to a sandplain at Oneida castle whose altitude requires a controlling barrier at not far from 600 feet. See also D. F. Lincoln: Geology of Seneca county, New York. State Museum Report, vol. 2, no. 48, 1894, p. 77.

level appears inadequate, it is to be remembered that the conditions did not favor uniformity in deposition or stability of waterlevel. The barrier which held the waters at this stage was doubtless of a somewhat transient nature. A straggling water body received contributions from fluctuating glacial drainage streams on its border, and perhaps suffered invasion from glacial ice itself. A progressive reduction of the baselevel may have exposed the heads of the deltas to dissection while their frontal portions were still receiving accessions of material. We are thus led to inquire as to the location and nature of the barrier. Gilbert suggests an ice dam in the lower Mohawk valley. This would be entirely adequate, but from his present knowledge of the facts the writer inclines to place the obstruction at Little Falls and to view it as composite in character. It is to be noted that the gorge is long, narrow, and sinuous. At the time in question the gneiss barrier would have stood at an altitude of at least 440 feet if the relation to the sealevel had been the same as at present, but the country was lower by whatever share this locality had in the Champlain depression. This diminished the rate of flow and may have made ice-gorging a most effective agent. Dana thus urges the importance of this means of blockade:

> "The obstructions in particular cases might have existed for a very long era, instead of for a few weeks, such as happens after a modern winter. Again, the slackened or suspended flow of the water, caused by such ice obstructions, would have favored the deposition and accumulation about them of drift, and some may have thus been converted into complete dams." *

Chamberlin and Salisbury admit blockade by ice-gorging to the extent of considerable flooding of the Driftless area.†

At Little Falls we have the most favorable conditions—a narrow gorge, toward which abundant waters moved—waters which in turn were bordered by glacial ice. It is as if Glacier bay, Alaska, were to be raised above sealevel and given a long, devious outlet a fraction of a mile in width. There is, however, an added consideration. The drift shoulder on the northwest of Little Falls has suffered severe erosion. The Calciferous cliffs on the south side have also been sapped to an unknown amount. The valley is now barely wide enough for the river and the various lines of travel. This passage was not unlikely completely blocked to near the present altitude of the shoulder or 808 feet. The barrier would then have been cut down like the blockade north of lake Bonneville, but probably much more slowly, being protected by grounded ice

* J. D. Dana: On the damming of streams by drift ice during the melting of the great glacier. Am. Jour. Sci., vol. xi, March 1876.

† Chamberlin and Salisbury: Driftless area of the upper Mississippi valley. Sixth An. Rep. U. S. Geol. Survey, p. 290.

above. If the barrier were below Little Falls, the corresponding water levels should be found below that place. Such have not been noted, though it has not been possible to make a careful study of the higher slopes. It would seem that powerful rapids led down to a lower water-plane, yet to be described, on the east. The gradual withdrawal of a tongue of ice from the upper Mohawk valley, as described by Chamberlin, would have left a local lake, in whose quiet waters the fine clays, with glaciated pebbles, between Utica and Little Falls, were deposited. Later the Mohawk channel opened to the drainage from the west and a vast body of fine sands, with varying gravels, were laid down in the great lake-like river which swept eastward. The sediments from the main flow were commingled with delta and terrace material from local sources. Any earlier or higher outflows to the east were probably temporary, leaving little record, until the 600-foot horizon is reached. Gradually the barrier was breached and the waters came down to the Iroquois level. Lake waters still extended eastward to Little Falls, owing to the presence of the gneissic barrier, and probably were maintained at that level through the lower valley for a considerable period.

LOWER MOHAWK VALLEY

East Creek delta.—This is a triangular area whose parts are symmetrically disposed on either side of the creek above its entrance upon the Mohawk. It has not been mapped, and was but partially studied. It extends northward about a mile and a half. Westward it is prolonged into a narrow, somewhat morainic shoulder toward Little Falls. Eastward it breaks into a decidedly morainic belt which extends to Saint Johnsville. The height at the front is 110 feet above the Mohawk flood-plain, or 440 feet above the sea. It is bounded along the valley by a steep erosion bluff.

Saint Johnsville bench.—At this village on either side of a local stream from the north is a somewhat morainic bench sloping toward the river and rising about 110 feet above the floodplain, or 430 feet above tide. A good section by the creek offers an exposure of 60 feet.

	Feet.
Fine, horizontally bedded sand, top................	27
Fine, thinly laminated black clay, without pebbles..	8
Very stony blue till	25

Fort Plain bench.—This extends, with uneven top, in a fairly continuous manner, nearly to Saint Johnsville on the west and eastward toward Canajoharie. It is bisected by the valley of Otsquago creek, but is only slightly related to it in origin. The Clinton Liberal Institute stands conspicuously on it, and the higher parts of the town both east and west. The height may be averaged at 125 feet, or 431 feet above sealevel. The chief and basal constituent of the mass is very stony till. This is usually overlain by a moderate though variable thickness of sands and gravels. Many exposures are afforded by the cuts of the West Shore railway. The high bluff facing the creek on the east side gives the following section:

	Feet.
Till, moderately stony, oxidized, scratches obscure, contains sandy layer....	10-15
Waterlaid material, light sands below, sandy clay above....................	15-20
Base, very tough, stony blue clay, stones freshly scratched............. ..	25-30

Cayadutta (Fonda) delta.—The term is used with qualification. In and about Fonda are massive stony tills, extending up the creek one and a half miles, the edges of the till showing ice contact rather than erosion. Rising out of the creek valley to the west a level tract stretches westward toward Yosts and the Noses fault scarp at an altitude of 440 feet. This area is well shown upon the Fonda sheet. The surface is sandy, free from stone, smooth as a floor, and rises gently to the lower slopes northward. The general section, as learned from a resident, is sand, 6 to 15 or 20 feet, then often gravel, followed sometimes by fine clay without stones. At a greater depth the till would doubtless be entered.

The deposits represent a lacustrine expansion of the river, when held at this level, aggrading to a uniform surface above the till. Some stone fences were seen, but it was learned that all the material was brought from the hills to the northwest.

Schoharie Creek delta.—The conditions are similar to those at Fonda, with massive till at the mouth of the valley, a slight bench on the east, and a large triangular area stretching westward, extending by Auriesville to near Fultonville, at altitudes ranging from 420 to 440 feet. The proportion of true delta material is not well determined, nor were good structure sections found. The Mohawk floodplain is very broad where the creek enters, and no doubt extensive deposits have been swept away. At the top of the drift bluff about Auriesville lacustrine clays and sands were found, apparently in the same relations as at Saint Johnsville and near Fonda,

Amsterdam benches.—At Aiken, 3 miles to the west, boulder-clay is overlain by highly inclined beds of sand and gravel. North of Spring street, in Amsterdam, and at the cemetery and "Cork hill" a very tumultuous assemblage of sands, gravels, and clays is found. The sections were somewhat obscured, but, without much doubt, till is overlain by stratified beds. The altitude is 420 to 440 feet. At the top of a similar shoulder on the south side 5 feet of pebbly loam are underlain by lacustrine clay of considerable thickness. Another section at Yankee hill cut on the West Shore railroad is as follows:

	Feet.
Pebbly loam	3
Waterlaid clays	5-10
Blue till	60

The clays near this point are used for making brick. They are very fine and absolutely free from pebbles. Eastward from Amsterdam no noteworthy marginal drift is found until Schenectady is reached.

Correlation of deposits in lower valley—440-foot level.—The dominant constituent is a massive basal till. The abundance of such material appears to be largely due to the free exposure of rocks by faulting. Overlying the till at several points we have found the fine clays, whose freedom from pebbles suggests that no glacier ice floated in the waters of the lake while the clays were laid down. The surface beds on all the marginal accumulations are sands and gravels. There is a striking accordance of levels thus:

	Feet.
East Creek	440
Saint Johnsville	430
Fort Plain	431
Fonda	440
Schoharie creek	420 to 440
Amsterdam	420 to 440

This corresponds well with the Iroquois plane, though not believed to be genetically related to it. The waters may or may not have fallen below this level before the barrier was cut to the gneiss at Little Falls. Whenever it took place a waterfall of 100 feet or more was inaugurated at that point, and the postglacial breaching of the gneiss was actively begun. The dam that held the lower Mohawk lake in place is unknown. Most naturally it would be the retreating ice of the Hudson valley, perhaps extending up our valley toward Amsterdam. Stagnant ice may have filled much of the valley during the aggrading of the marginal drift, though the ice contacts have largely been cut away by later erosion. The benches, it is evident, are not kame terraces, nor are they in any true sense river terraces. The lake may not have originated and grown by uniform extension eastward, but may have begun at several points, as at the confluence of lateral valleys, these local lakes gradually merging as the ice melted out. The lake may have come more or less fully into existence before the drainage of the great lakes found an eastward outlet.

Aqueduct barrier—340-foot level.—The next stage was the subsidence of the lower Mohawk waters to the plain of 340 feet. This is the altitude of the great mass of sands which girt the south and east of the broad basin in which Schenectady lies. A reference to the Schenectady sheet will render detailed description unnecessary. It was here, as has long been held, that the Mohawk was jostled from its more southerly preglacial course and sent toward Cohoes. For the most part rock lies at no great depth at Schenectady. The old channel is probably westward from the city, where at the city waterworks the following section was revealed by well boring.* The mouth of the well is 34 feet above the river.

	Feet.
Red clay and loam	12
Gravel	68

Rock was not reached. Across the river from Schenectady westward a broad ridge of sand (so far as seen) about 60 feet high extends 3 miles up the valley between the river and the Central railway. It is perhaps a bar or shoal built into the lake at the mouth of the valley while the waters held the 340-foot level. This must have been maintained for some time, for the lowest point was found at Aqueduct, 4 miles northeast of Schenectady, where the river has cut a postglacial gorge 135 feet deep into rocks of Hudson River age. Traces of this level have been discerned up the valley, near Fort Plain and at other points. The Aqueduct barrier ponded the waters westward to the base of the gneiss at Little Falls. The valley of Alplaus kill, which joins the Mohawk valley above Aqueduct, offers a passage slightly lower than 340 feet. Whether this continues northward and eastward to the Hudson is not known. In any case the receding ice-front in the Hudson valley would have served as a dam for a time, until erosion at Aqueduct provided at that place the lowest point of overflow.

Considering the amount of postglacial work at Aqueduct, it is quite possible that a lake, contracting in depth and in westward extension, persisted until the end of the Iroquois stage, or even later.

A striking similarity of conditions appears at the head of the upper and lower Mohawk deltas (see figure 2). In both cases the river emerges from the plateau by a narrow valley, swings broadly around through a bowl bordered by a steep escarpment of drift, and passes through a postglacial rock gorge. In both cases the river seems to have been driven from a more westerly course by a blockade of drift and a lake has been maintained during the erosion of the gorge, except so far as the bowls

*Obtained by the courtesy of Superintendent George T. Ingersoll.

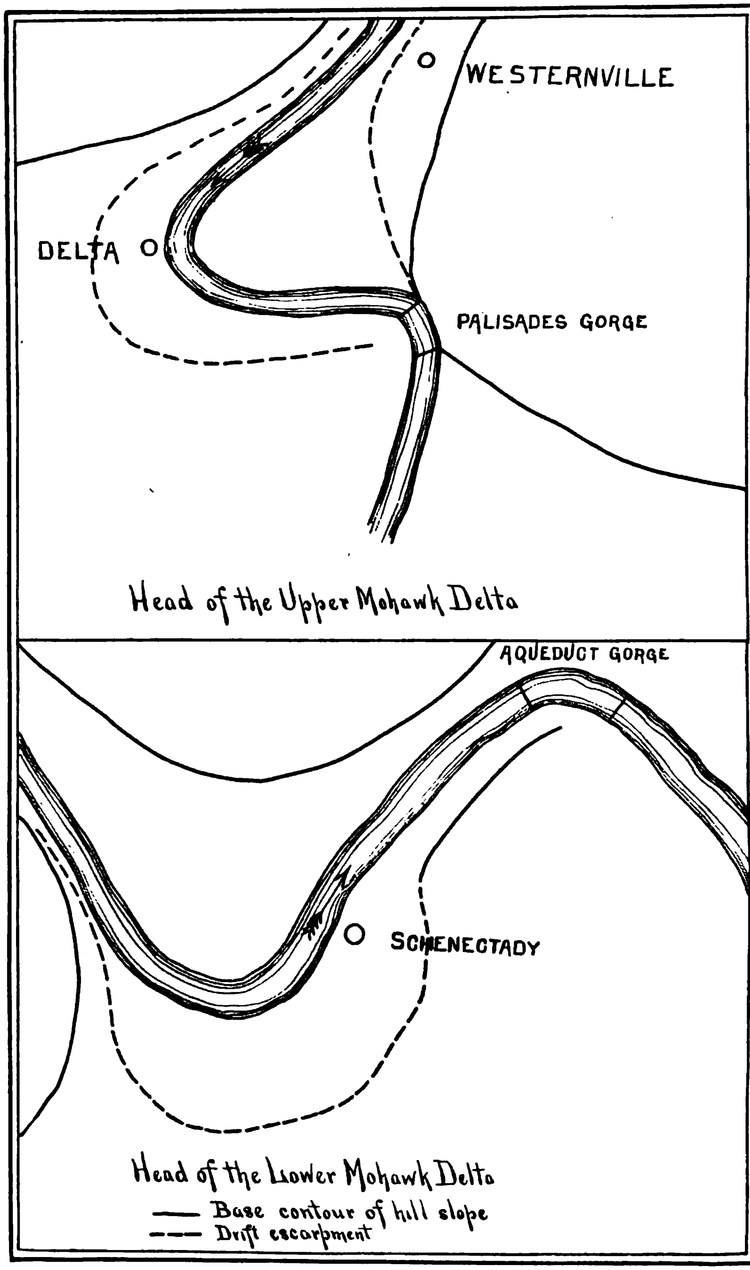


FIGURE 2.—*Heads of the upper and lower Mohawk Deltas.*

may have been filled, but later opened and their edges rimmed out by the stream.

It is not in the plan of this paper to discuss the delta of the lower Mohawk. The character and extension of the deposits which belong to it and their relations to the other Pleistocene materials of the Hudson valley offer an adequate field for a separate investigation.

Various flood gravels.—Various gravels along the valley receive brief reference. East of the Little Falls gorge is the small moraine described by Chamberlin and south of it along the valley side a somewhat morainic accumulation, not sufficiently observed to warrant a detailed notice. Large boulders of gneiss are associated with coarse gravels, a natural product of the vigorous glacial and aqueous erosion of the gneissic barrier to the west.

From East creek to near Saint Johnsville there extends for two miles a somewhat uneven terrace of coarse, indurated, horizontally bedded gravels, from 40 to 60 feet high. Its origin is not clear. It may be a remnant of a much more extensive sheet of gravel, as there are indications of terracing upon the erosion cliff along its southern border. It may be derived from the East Creek valley. The plentiful exposures of limestone in that valley, taken with the extensive induration of the gravel seen where the Central railway has excavated for ballast, emphasizes this suggestion.

A very interesting gravel bed runs from the big Nose on the north side past Yosts station. It is three-quarters of a mile long and has been opened for nearly its entire length for the railway and to the depths of from 5 to 20 feet. The valley bottom abruptly widens from a quarter of a mile at the Noses to nearly three-quarters of a mile here, though the Calciferous cliffs still rise on the north. The railway runs between the gravel bed and the river, whose flood waters never now quite reach the track. Except at the west end, where it is a few feet higher, the gravel rises about 8 feet above the present floodplain. The material is fine, very uniform, with a sandy matrix, and pebbles rarely exceeding an inch in diameter. The gravel is so clean to the top as to support only a spare growth of weeds. Along the north border the surface slopes gently toward the base of the cliff. Fresh exposures by the steam shovel show the same inclination of the strata. A long and very fine exposure near the middle of the mass shows the beds inclining down the river from 3 to 4 degrees, with elaborate displays of cross-bedding. The whole appears to be an alluvial apron made by the flooded Mohawk. As the pent up stream emerged from the narrow channel between the shores it dropped its well worn burden into the more quiet waters below, waters which were perhaps lacustrine, held up by the still persisting rock barrier at Aqueduct.

Fluvial stage.—North of the above gravel bed, midway, in a triangular recess between it and the cliffs, are some kame heaps rising 60 to 70 feet from the top of the gravel. Their sides are not abraded, and the lateral slope of the gravel plain toward their base also suggests that the river flood could not have risen, unless for short intervals, much above the present surface of the gravels. In a similar recess on the north side, west of the Nose and west of a creek entering from the north, are similar mounds, of which the highest rises to an estimated height of 80 feet. Their position in a kind of recess may have been a partial protection, but repeated observation confirms the impression that a swift and powerful current could not have left their slopes unharmed had it risen upon them for any length of time after lacustrine conditions ceased.

MASSIVE LACUSTRINE CLAYS

No reference, except by way of record, has thus far been made in this paper to a few deposits of massive clay, indicating long intervals of quiet deposition. Well records have not disclosed the presence of such deposits in the valley to such a degree as had been anticipated from studies in the region to the southward. Such clays appear at Sylvan beach, Rome, Herkimer, and in some of the wells at Ilion and Frankfort. Of the wells disclosing thick masses of lacustrine clay, not one is midway of the valley, but all are either on the edge of the floodplain or beyond. The well at the Ilion Typewriter works was sunk 195 feet to rock without encountering clay. Either, therefore, the clay was never a continuous deposit or it has suffered erosion. If the former, it was laid down in local, marginal lakes, but the thickness, especially at Herkimer, is not favorable to this supposition. The hypothesis of erosion is favored by the conditions at Ilion. At the south edge of the floodplain is the well at the typewriter works. Within a mile and a half southward massive clays occupy almost all altitudes, from 70 feet below the river floodplain to 200 feet above it. It is also significant that at Herkimer 100 feet of clay are underlain by 30 feet of gravel, including a boulder 7½ feet in diameter. At one of the Rome wells, also, 65 feet of clay and quicksand are underlain by 31 feet of hardpan. These facts look toward an early period of low altitude and slack drainage preceded by active glaciation and followed by erosion and glacial deposition. If an erosion of the clays took place in the Mohawk valley, it was in part glacial, as is shown by the presence of the rock basin in the valley east of Utica.

In an earlier paper the writer has reported a series of well records from

Chenango valley.* Little of inference was there drawn from the presence of massive beds of fine clays underlying the gravels throughout the valley. They are of such depth and apparent continuity as to suggest a single and contemporaneous origin. The gravels, on the other hand, overlie the clays abruptly, show a high gradient, and kames and kame terraces at short intervals from Deansville to Binghamton were made in the presence of glacial ice. The case is similar for the Unadilla valley, though little study has been given to it. The writer has information of a bed of more than 300 feet of clay at Leonardsville, in the Unadilla valley, 10 miles south of the col at Richfield Junction. At the col, rock is reported at a depth of 30 feet. These facts, compared with the rapid ascent of the rock bottom to the surface in the Chenango-Susquehanna confluence at Binghamton, suggest that there may be long and shallow rock basins in these valleys similar to that east of Utica. Much additional study would be needful to prove this, but in any case the clays point to a depression much earlier than the Champlain, so fully described by Chamberlin and Leverett for the west and indicated by Shaler and Woodworth for southern New England.†

SUMMARY

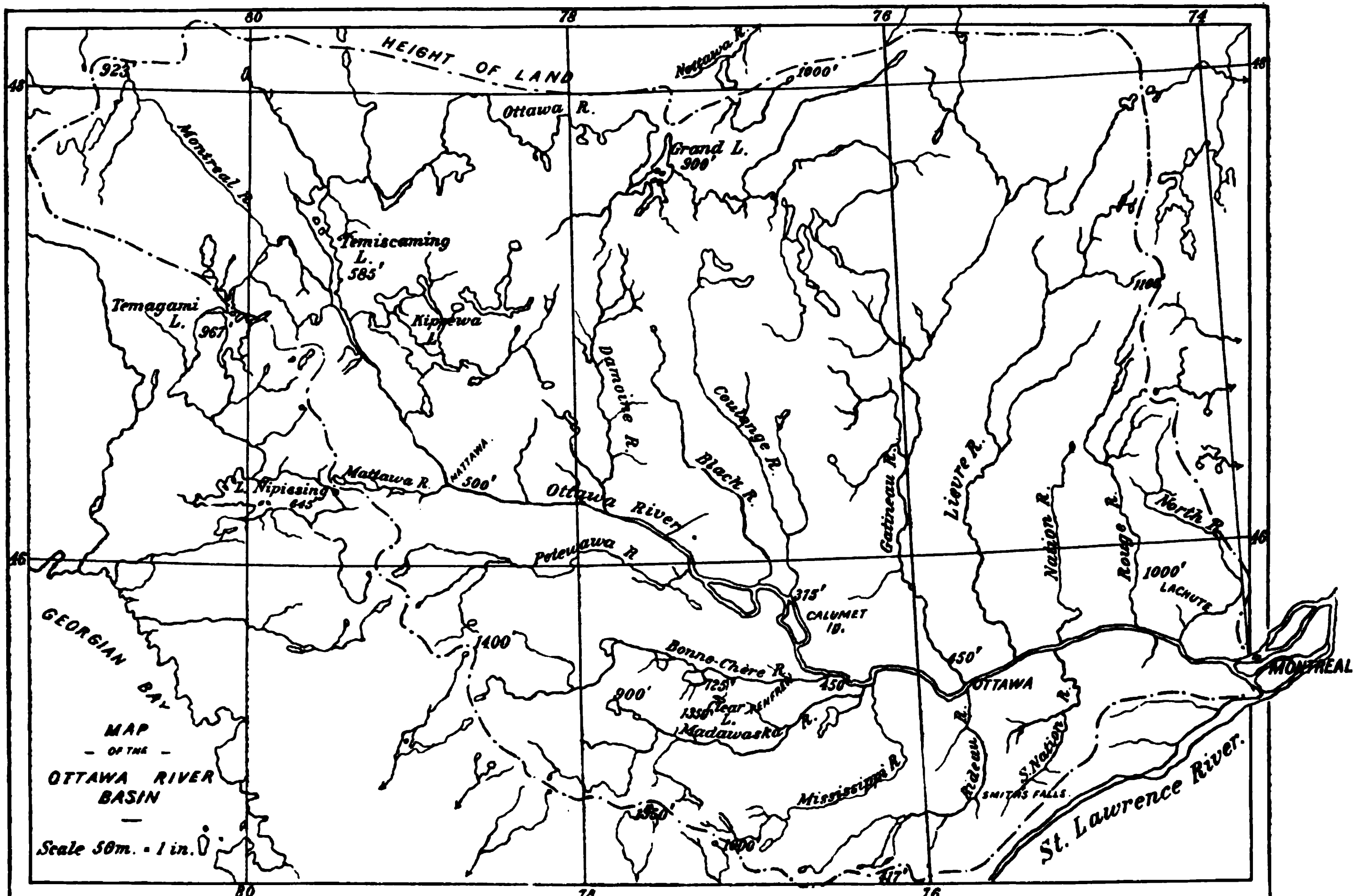
The lower Mohawk and a corresponding valley to the westward are considered as subsequent in character, having been initiated by headward cutting from the ancient Hudson and Saint Lawrence valleys, along the strike of soft beds to the col located by Chamberlin at Little Falls. The Adirondack streams consequent on Paleozoic topography were thus diverted and the Susquehanna streams were beheaded. West of Little Falls the rock floor descends toward lake Ontario, but not uniformly, a buried rock basin nearly 150 feet in depth lying east of Utica. The present arrangement is due to glacial and aqueo-glacial erosion at Little Falls, and to aggrading from Rome eastward by glacial materials. The westward flow of the lower Mohawk glacier is confirmed by striation at Amsterdam.

The drift deposits west of Little Falls are largely composed of deltas and benches whose altitudes indicate approximately a waterlevel of 600 feet. This is believed to represent a lacustrine stage in which the waters had fallen below the Warren level and below Fairchild's Geneva beach, but had not yet subsided to the Iroquois plane. The dam is thought to have been at Little Falls, and of a composite nature, the sill of gneiss

* Glacial flood deposits in Chenango valley. Bull. Geol. Soc. Am., vol. 8, pp. 27-29.

† N. S. Shaler, J. B. Woodworth, and C. F. Marbut: The glacial brick clays of Rhode Island and southeastern Massachusetts. Seventeenth Ann. Rep. U. S. Geol. Surv., pp. 951-1004.

then standing at about 440 feet, with drift and ice blockade in the long, sinuous, narrow gorge. Below Little Falls marginal bodies of massive till, aggraded by water-laid material, show a fluvio-lacustrine level of 430 to 440 feet, the barrier being unknown. The next stage in the lower valley was also fluvio-lacustrine at 340 feet. The gneiss then caused a great waterfall at Little Falls, and the lacustrine stage persisted to the eastward, while a rock gorge more than 100 feet deep was cut at Aqueduct near Schenectady. Certain beds of massive water-laid clay west of Little Falls, taken with similar deposits in the Chenango and Unadilla valleys, are thought to show long and quiet deposition, with perhaps considerable later erosion before the last advance of the ice across central and southern New York.



MAP OF THE OTTAWA RIVER BASIN

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 9, PP. 211-222, PL. 16 FEBRUARY 22, 1898

SANDS AND CLAYS OF THE OTTAWA BASIN

BY R. W. ELLS

(Read before the Society December 28, 1897)

CONTENTS

EXTENT AND ROCKS OF THE AREA

The basin of the Ottawa river forms a somewhat extensive area of not far from 60,000 square miles. It includes various geological formations, which range from the oldest crystallines or Fundamental gneiss to the upper Silurian. All varieties of rock are found, including gneiss, granite, and the eruptives of the Laurentian and Huronian systems, with crystalline limestones and schists of several kinds. The softer strata of the Paleozoic formations are all represented in the area, and comprise sandstones, shales, slates, and fossiliferous limestones. As the whole area has been extensively glaciated, there must of necessity be very considerable differences in the products of decomposition resulting from the several agencies to which they have been exposed.

Physical Features of the Ottawa Basin

PREVIOUS INVESTIGATIONS AND THEIR RESULTS

In the "Geology of Canada"* the distribution and origin of the sands and clays of the lower Ottawa and Saint Lawrence basins were very fully discussed, in so far as the explorations of that district had then been prosecuted. The area along the lower Ottawa there described was comprised chiefly in the generally level portion between the Rideau and the Saint Lawrence, as but few attempts had at that time been made to penetrate the wilderness country to the north and west. Within the last twenty years, however, most of the large streams which traverse the country to the north and south of the Ottawa have been examined, and in many cases these have been followed to their sources; and in this way a large amount of interesting and valuable information regarding the physical features of these comparatively remote and hitherto unknown regions has been collected by the several observers in this area, and many new facts of interest relating to the great questions of glacial and postglacial geology have been obtained.

THE UPPER OTTAWA

The peculiar course of the Ottawa in its upper portion, to the north of lake Temiscaming, forms, by its doubling on itself in its lower or eastward stretch, a loop-shaped area, extending eastward from that lake to the Gatineau, one of the principal tributaries from the north, which enters the Ottawa river near the city of Ottawa. In this loop are included several large streams or branches, some of which extend almost entirely across the area. Among these are the Kippewa, the Black, the Dumoine, and the Coulonge, all of which have large tributaries and drainage basins. Some of these streams have apparently exercised an influence in determining the present channel of the Ottawa, in connection with which a number of old and now partly filled channels can be easily recognized at different points between the outlet of lake Temiscaming and the Saint Lawrence river.

HEIGHT-OF-LAND, LAKES AND RIVERS

The height-of-land which divides the waters of the Ottawa basin from those which flow into James bay on the one hand, or into the lower Saint Lawrence on the other, is found a short distance to the north of the upper or westward course of the stream.

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*Geology of Canada, 1863, pp. 916–920.

Along the upper portion of the river several large lakes are encountered, often of the nature of river expansions, among which the Grand lake is one of the most important. The elevation of this lake is given by Dr Bell as about 900 feet above sea, and the height-of-land along the upper stretch of the Ottawa as ranging from 850 to 1,050 feet. The ridge separating the southern waters from those flowing north is low and sandy, and it is probable that the waters of this lake at one time flowed northward into James bay. Dr Bell remarks on this point that the outflow of Grand lake was at one time through the same physical depression in which the lake is now situated, and that this outflow has been arrested by the silting up of the channel at the spot where the waters now divide, owing to a slow differential elevation of the land to the northeast, which is still going on.*

The greater portion of the area enclosed by the two stretches of the Ottawa, east of lake Temiscaming, is occupied by numerous lakes, often of large size and frequently with sandy shores. This part of the basin is underlain almost entirely by crystalline rocks, chiefly gneisses and granites, with occasional bands of limestone of Archean age.

To the north of the city of Ottawa the height-of-land is about 230 miles distant. The eastern limit of the Ottawa drainage area is marked by the waters of North river, which lies northwest of Montreal, and which enters Ottawa river about 30 miles west of its junction with the Saint Lawrence. The elevation of the height-of-land in this direction, separating the southern flowing waters from those of the Saint Maurice, is between 1,100 and 1,200 feet.

West of lake Temiscaming, which has an elevation of 585 feet, the height-of-land between the Ottawa waters and those flowing into James bay and into lake Huron is about 50 miles distant. The eastern portion of this watershed contains the Montreal river and its tributaries, with several large lakes, among which is lake Temagami, the waters of which discharge to the south into lake Nipissing and to the northeast into lake Temiscaming. The elevation of lake Temagami is, according to Barlow, 967 feet above sea, and that of the height-of-land to the north of lake Temiscaming is about 923 feet. A curving line indicates the watershed between the head of Montreal river and lake Nipissing, the elevation of the latter being only 645 feet. The elevation again rises eastward of this lake till at the source of Petewawa and Madawaska rivers it is about 1.400 feet, whence it gradually declines toward the Saint Lawrence, being only 417 feet at the headwaters of the Rideau.

South of the Ottawa the area comprised in the drainage basin includes a large proportion of the Paleozoic rocks. The western part, in the coun-

*"Recent explorations to the south of Hudson bay." Geographical Journal, July, 1897, pp. 5, 6.

ties of Addington and Hastings, is, however, occupied by the Archean, and this produces, over a considerable area, some of the roughest surface in eastern Canada. The streams which flow thence into the Ottawa are not so large as those in the northern portion of the basin, but are still of good size, and comprise the Petewawa, Madawaska, Mattawa, Bonnechêre, Mississippi, Rideau, and South Nation.

To the north of the Ottawa the principal streams east of the Gatineau are the Lievre, North Nation, Rouge, and North. These all head in the Archean highlands, and traverse the crystalline rocks to within a short distance of their junction with the Ottawa. Of these the Lievre is the longest, and has its source near the headwaters of the Gatineau and Saint Maurice.

General Character and Distribution of the Clay Deposits

Over much of this large area, both to the north and south of the Ottawa, deposits of clay are found. This clay is usually of the blue variety, similar in character to much of that which occupies the valley of the lower Saint Lawrence. It is found on all the streams, frequently underlying great areas of sand and gravel, as far as the height-of-land in the north part of the basin, so that it is evident these deposits are very widespread. They are frequently well stratified, layers of sand and fine gravel alternating with the clay in the upper part of the latter, but the lower portion of these deposits is almost entirely a firm blue clay. Along the line of the Ottawa and Parry Sound railway these clays are seen as far west as Barrys bay, which is on the upper waters of the Madawaska, underlying the sands at an elevation of over 900 feet above sea, the elevation of Barrys bay station being 937 feet.

Along some of the rivers, as the Gatineau, the extent and thickness of these clay deposits are very great. On the line of the Gatineau Valley railway there are cuttings in the first 50 miles north of the Ottawa in this material fully 100 feet deep, overlaid with sands at a number of points, while on the Bonnechêre, in the flat area west of Renfrew, the thickness, judging from the sections along the river courses, must be equally as great.

General Character and Distribution of the Sands

The overlying sands are well seen along the streams on both sides of the Ottawa river, and they form a widespread mantle extending beyond the height-of-land. They are usually fine grained and in places, as along the river above Pembroke, they have a thickness presumably at least of 100 feet. They not only occur at these high elevations, but are also well developed in the lower Ottawa basin, forming extensive areas throughout the country, both to the north and south of the river below Ottawa city.

In places they are loosely coherent, and when once disturbed they blow about under the action of the wind like fine snow. Good illustrations of this feature are seen to the eastward of the village of Lachute on the north side, as well as at several points on the south side of the Ottawa river, where the sands often form large areas through which the streams have cut deep channels into the underlying clays.

The country north of the Ottawa for the first 40 miles is generally hilly and rough. North of this the surface assumes more the aspect of plains, consisting largely of these sands, through which hill ranges and isolated peaks protrude, some of which reach elevations of 2,500 feet above the sea. This character of country extends from the vicinity of Rouge river on the east to beyond lake Temiscaming on the west, and extends north as far as our observations have been made.

On the south side of the Ottawa this sandy character is also well seen along the upper portion of the river, about the Petewawa, and in the area between this stream and the Bonnechêre. In some of the rivers, like the Black, the stream flows almost entirely between banks of sand, except where heavy rapids and falls are caused by rocky spurs from the adjacent mountains which form barriers across the course of the river.

Fossiliferous Characteristics of the Clays and Sands

The clays of the lower Ottawa and Saint Lawrence basins frequently contain marine shells, though this feature is by no means of universal occurrence. The deposition of these clays about the city of Montreal has been well stated in the "Geology of Canada" (1863), as also by Sir William Dawson in his "Canadian Ice Age" (page 201). From the latter we find that marine shells are well exposed on the slopes of the Montreal mountain at an elevation of 560 feet above present sealevel, while markings, indicating the presence of floating ice, are recognized at an elevation of 750 feet. Throughout this district there are great expanses of marine clays which show no trace of organisms, while very often the overlying sands and gravels hold great quantities of marine fossils. Well established outcrops of these shell-bearing sands are found along the upper Ottawa at elevations of 470 feet along the summit of rocky ridges west of Arnprior, while the clays in the valley alongside are apparently barren. The most westerly point where shell-bearing clays were noted in this direction was near the village of Bryson, about 50 miles west of Ottawa, where a small outcrop of shells was seen on the road east of the river, though in the clays of the river expansion, known as lake Coulonge, some 20 miles west of this place, at a still higher level, or about 370 feet above the sea, fish-bearing nodules are obtained similar to those so abundant in the vicinity of Greens creek a short distance below Ottawa city. Along the line of the Gatineau Valley railway also this barren aspect of the marine clays is a marked feature. In none of the cuttings along this section, although they are numerous for many miles, were fossils found, except at the summit of a sand and gravel excavation near the village of Chelsea, at an elevation of about 450 feet. A few miles east of this place, near Cantley, the clays contain a few shells at about the same height, while at the outlet of McGregor's lake not far distant a great quantity of shells were observed, apparently from the sands of this area and at the same elevation. There is no break apparent in the deposition of these beds, from the nodule-bearing clays near Ottawa to the most northerly outcrops on the Gatineau and the Lievre where the clays are, in so far as yet known, all barren.

The origin of these apparently barren sands and clays over such wide areas has been a subject of discussion for some years and has given rise to considerable diversity of opinion. Their extension northward beyond the height-of-land towards James bay, where they are apparently similar in character to those along the Ottawa, and their presence over so large an area to the south of that river give these deposits a breadth of some hundreds of miles from north to south, with a corresponding extent from east to west.

The denudation must therefore have been enormous over a very large area, and in support of this view it may be mentioned that outliers of the Black River limestone are found at many points from the lower part of the Ottawa to lake Nipissing, sometimes in areas of considerable extent, while in other places the exposures are limited to only a few hundred square yards. The inference therefore is that this formation, as well as several of those which overlay this to the upper Silurian, once extended over a large portion of the Ottawa basin, and these have in great part been removed, so that only comparatively small portions of these sedimentary formations now remain.

Evidence as to the Origin of the underlying Clays

The underlying clays at the higher levels up to nearly one thousand feet, and in places to a height considerably more than this, are apparently continuous with those of undoubted marine origin to the north and east, and the inference naturally follows that all these deposits were laid down by the same agencies. The absence of marine organisms over a large part of the area is only negative evidence to the contrary, and there are certain facts that go far to establish this theory of their marine deposition.

In support of this view we may mention that all the evidence points to the fact that the estuary of the lower Ottawa was continuous in immediately Postglacial times, as it is at the present day, with that of the lower Saint Lawrence, and that there is no evidence to show that these two basins were ever separated subsequent to the Glacial period.

The observations of Mr R. Chalmers along the lower Saint Lawrence and throughout that portion of Quebec to the east have clearly proved that there has been a submergence of this whole area now occupied by the Saint Lawrence basin to a depth of nearly or quite 1,000 feet, as indicated by well defined marine beaches which front the present Saint Lawrence valley. The indications of this submergence are equally clear on the west side of this river, and, tracing this old shoreline westward up the Ottawa, the same observer has recently found equally good evidence in the form of beaches that this submergence extended westward, as these lines facing the open estuary of the Saint Lawrence were noted at an elevation of about 1,000 feet in the area to the north of Lachute, about 40 or 50 miles west of Montreal. The presence of old beaches, well defined, can also be readily recognized at a number of points west of this, above the city of Ottawa, and it thus appears that the waters of the postglacial ocean extended westward to a great distance. A submergence of 900 to 1,000 feet would carry the waters of the Ottawa estuary well over the height-of-land to the north and thus connect these with the waters of James bay.

Sand and Clay Deposits South of the Ottawa

The Bonnechêre river, one of the tributaries of the Ottawa from the south, presents several interesting features in this connection. To the south of the town of Pembroke a great part of the surface to the north of Golden and Round lakes, which are expansions of this stream, as also the country along the course of the river west of this point, are covered with a great thickness of sand, and this deposit extends south to the foot of the Brudenell range of hills about 12 miles south of the Bonnechêre river. These sands are well exposed in the valley of Clear lake, which lies along the foot of the mountain ridge in the township of Sebastopol, and the sands extend for many miles in either direction. The elevation of Clear lake is 745 feet above sea, and between this and the Bonnechêre to the north the deposits of sands and clays are almost continuous. A short distance east of these the clays of the lower Bonnechêre, west of Renfrew, come in, and are apparently continuous with those of the area about Clear lake. From the aspect of the whole country in this direction it would appear as if the waters of the whole Ottawa basin extended to the range of the Brudenell hills, and that the area was directly open to the Saint Lawrence. The elevation of the Brudenell ridge is about 600 feet above Clear lake, or rather more than 1,300 feet above the sea.

In traversing the valley of the Ottawa from lake Temiscaming east, nearly to its mouth, one of the most striking features in this connection is the presence of former channels. These have now, to a large extent, become filled with sand and gravel. The valley of the Ottawa itself is a very old one, since the Paleozoic formations as far back as the Calciferous, have been deposited there subsequent to its delineation. Along that part of the river between the Rapides des Joachim and High View, which is about 20 miles west of Pembroke, the channel is now very deep, and this portion goes by the name of the "Deep river." The river in this part follows a nearly straight course for 30 miles, and the hills on the north side are in places nearly 1,000 feet high. The south side, however, is generally low and comparatively level, with great areas of sand plains. Above High View there is a depression on the south side which leads into the lower part of Chalk river, and here the sand deposits are very heavy. This depression at one time apparently formed one of the channels of the Ottawa. Similar old channels are to be seen at the Roche Capitaine and at the Des Joachim, which are farther west. A very pronounced old channel, now blocked with sand and gravel, is seen at Pembroke, where the river in its present course sweeps off to the north along the south side of Allumette island. The old Pembroke channel kept a nearly straight line for 30 miles, and is now indicated by the Muskrat river and lake and by a chain of small lakes which extends eastward past the great bend around the east end of Calumet island. Many of these small lakes in the line of the old channel are reported to be of great depth, and these are now separated by sand bars. The country along the present channels of the river from Bryson west is now largely sand-covered on the north and clay-covered along the south shore. The channel of the Ottawa on the north side of Calumet island is almost entirely in sand, while the greater portion of Allumette island, opposite Pembroke, is also largely occupied by sand deposits.

Along the valleys of the Ottawa and of its several tributary streams these sands and gravels, as also many of the clays, are underlain by deposits of boulder clay, and on the north side of the Brudenell ridge a thick deposit of black clay apparently represents the decomposition in place of thick beds of Utica shale which are found along the north side of the range to the south of Clear lake, resting against the gneiss and granite of the mountain. This valley was at one time evidently largely filled with sands. To the south along the crest of the range are huge blocks of limestone of the Black River formation which have apparently been derived from outliers of these rocks, now found in the low area to the north and which must therefore have been carried upward at least 500 to 600 feet to their present position.

Kames of the Region

Size and Distribution

Kames, often of large size, are found at many points. Some of these are of fine material, while others are coarse and contain quantities of well-rounded stones. The direction of many of these kames is nearly east and west, but in places they have a course nearly at right angles to this. They are often of large size and some of them have a height of not far from 100 feet. Some of the longest and best defined extend nearly along the river valleys in which they are found.

Origin of the Kames

The kames of eastern Canada appear to be due to two causes. Some of them, more especially in the western portion of Ontario, are doubtless connected with glacial phenomena, while in the lower Ottawa and Saint Lawrence basins they owe their origin apparently to agencies subsequent to the Glacial time. This feature is well pointed out by Mr Robert Chalmers in his report on northern New Brunswick and Gaspe,* in which he cites numerous instances of kames which are more recent than the boulder-clays of that district, and which he unhesitatingly classes under the head of marine deposits. From recent study of the glacial phenomena of the Saint Lawrence and Ottawa basins Mr. Chalmers has also obtained certain facts that show that these deposits. as seen in the vicinity of Three Rivers and to the north of this place along the Saint Maurice, are well below the horizon of the shell-bearing Saxicava sands and marine clays, and are newer than the glacial deposits of this area. This view is also supported by the presence of marine fossils in the clays underlying the kames at various points, as well as in certain of the kames themselves.

Evidence as to the Submergence of the Ottawa Basin

The observations of Sir William Dawson on the Pleistocene deposits of the lower Saint Lawrence, in the vicinity of the Saguenay, have a

* Annual Report, Geological Survey of Canada, new series, vol. ii, 1886, pt. M, pp. 22–27.

manifest bearing on the subject under consideration. Sir William, in his "Canadian Ice Age," records the finding of marine shells in this district at elevations of 600 feet, where they are overlain by a great thickness of sands, similar to those which occur in the western area, and which form well defined terraces to a height of 1,000 to 1,200 feet above present sealevel, so that the elevations of these sands correspond very closely throughout an extent, from east to west, of many hundreds of miles.

The presence of scattered blocks of Laurentian rocks over the slopes and along the summits of the mountain ranges in the eastern townships of Quebec, at elevations from 500 to 1,200 feet, which present all the features of being left in their position through the agency of drift-ice, is strong evidence also in support of the theory of a great submergence over the greater portion of eastern Canada.

The finding of the bones of the whale in the gravels of the great kame-like ridge near Smiths Falls, to the southwest of Ottawa, at an elevation of 440 feet shows that the seas must at that time have been at a higher level than the present elevation of lake Ontario.

Dr Bell also records the presence of marine deposits in the country to the north of lake Superior, along the Kenogami river, at an elevation of 450 feet above sealevel, where they are also overlain by the usual deposits of sand.*

In this connection it may also be mentioned that Mr A. P. Low, in his report on the areas to the north of the Saint Lawrence, along the line of the Quebec and Lake Saint John railway, found unmistakable evidence of submergence to a depth of at least 600 feet above present tide, well defined shell-bearing beds occurring along the line of the railway at elevations of at least 515 feet,* the marine terraces associated with them being readily traced to a considerably higher elevation. Above these terraces beds of sand, similar to those so abundant throughout all the country to the north, continue to the headwaters of the Saint Maurice, Gatineau, and Ottawa. A portion of these sands seen along the latter river in the vicinity of Arnprior, which is about 40 miles west of the city of Ottawa, was at one time regarded as the eastern extension of the Algoma sands, and they are so depicted on the map which accompanies the atlas published by the Canadian Geological Survey in 1863. Recent investigations in this area have, however, shown the presence of marine shells in a portion of these sands at this place, and they must now in consequence be placed among the marine deposits. These are undoubtedly the same sands so conspicuous at many points

*Report of Progress, Canadian Geological Survey, 1895–'96, p. 340.
†Annual Report, Geological Survey of Canada, vol. v, 1890–'91, pp. 546 to 646.

in the lower Ottawa basin between that river and the Saint Lawrence, where the shells are very abundant in certain layers. They continue westward for a long distance along the line of the Canadian Pacific railway, and west of Sharbot lake and to the north of Kaladar station, which has an elevation of 702 feet, they are well displayed along the road to the village of Cloyne, near the upper portion of the Mississippi river.

Beaches of the Ottawa Basin

Near this village of Cloyne there are also well defined beaches at an elevation of not far from 1,000 feet above sealevel, the surface of the country over many acres being covered with well rounded beach stones. This elevation corresponds closely with that noted by Mr Chalmers between Montreal and Ottawa, and supports the view that the waters of the sea extended at one time over all this portion of eastern Canada. There is, moreover, no well defined break in the deposits in this direction by which the sands and clays along the lower Ottawa can be separated from those in the direction of lake Ontario, and it is presumable therefore that future observations will result in finding marine forms in some part of this more western area.

Drift Boulders of the Ottawa and Saint Lawrence Valleys

An interesting series of deposits is to be seen in that portion of the basin between the lower Ottawa and the Saint Lawrence. Here there are numerous ridges of drift boulders, some of which are of considerable extent, with elevations of 50 feet or more above the surrounding marine clays. These are possibly old moraines, around which the clays and shell-bearing sands have been deposited, but the distribution of certain of these boulders over the surface of the clays must be due to some other cause subsequent to the Glacial time.

Glacial Striæ

It is interesting to note that two well defined series of striæ can be recognized in the Ottawa basin. Of these, one follows closely the depression or valley of the Ottawa from the foot of lake Temiscaming to near its junction with the Saint Lawrence, the course of the markings being only a few degrees to the south of east, while the other set has a direction nearly at right angles to this, ranging from south to south sixty degrees west. From the difficulty of finding both these sets on the same exposure it has not as yet been practicable to definitely decide which of these is the more recent, since subsequent to the passing of the glacier many changes have taken place, due to the later period of submergence.

Conclusions

From the physiographic conditions of this portion of Canada it would therefore appear that the Saint Lawrence and the Ottawa rivers constituted a broad open estuary extending eastward to the sea, and that the waters of the ocean at one time continued westward into the upper Great lakes. In Quebec, east of the Notre Dame range of mountains, in the eastern townships, a somewhat similar estuary apparently extended into the waters of the gulf of Saint Lawrence, following the depression of the upper Saint John river. It is also probable that some of the divergent ice-markings in the area comprised in the lower Ottawa and Saint Lawrence basins were caused by masses of floating ice subsequent to the period of general glaciation, and to this cause is apparently due the distribution of many of the masses of Paleozoic limestone and crystalline rocks which are now found in places resting on the marine clays and Saxicava sands, not only in eastern Ontario, but at many points in the eastern townships of Quebec, since their present position can only be accounted for by the agency of some cause subsequent to the deposition of the boulder-clay, and as a consequence at a time more recent than the period of glaciation of the Ottawa and Saint Lawrence basins.

It does not fall within the scope of this paper to discuss the sands and clays of the great lakes. These are fully described in the Geology of Canada,* in so far as the information available at that time permitted. From the descriptions there given it would appear that there are two series of deposits, of which the lower or Erie clays are unconformable to the upper or brown clays. The Erie clays are very similar in character to those seen along the Ottawa and the Saint Lawrence, but they have not as yet, in so far as reported, yielded marine organisms. This is, however, only negative evidence, and it is probable that the Erie lower clays are the true representatives of the marine clays of eastern Canada. If the theory put forward that the ocean waters extended westward throughout the upper Ottawa basin to an elevation of 1,000 feet above present sealevel is the correct one, this hypothesis may well be maintained. It is presumable that the upper series of clays, with sands, may have been deposited as fresh-water conditions asserted themselves on the elevation of the land after the period of greatest submergence, but further detailed work in this area will be necessary before final conclusions can be stated.

* Geology of Canada, 1863, pp. 896–907.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 9, PP. 223-238 FEBRUARY 24, 1898

CLASTIC HURONIAN ROCKS OF WESTERN ONTARIO

BY ARTHUR P. COLEMAN

(*Read before the Society December 29, 1897*)

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RESULTS OF PREVIOUS WORK IN THE REGION

The rocks of western Ontario have been more or less carefully examined by several geologists, such as Bigsby, Bell, and Dawson, but the first detailed mapping of the region was done in 1883 and succeeding years by A. C. Lawson, who laid an excellent foundation for the future study of the Lake of the Woods and Rainy Lake districts.* Since then adjoining districts have been mapped by W. H. C. Smith and W. McInness, and special portions have been studied by H. L. Smyth, Winchell and Grant, and the present writer. The general conclusions reached by Lawson have been commonly accepted by those who have followed and will be made use of largely in the present paper, though most of the

* Geol. Survey of Canada, 1885, part CC; and 1887, part F.

facts employed have been observed by the writer while engaged in field work for the Ontario Bureau of Mines.

Classification of the Rock Series

Lawson describes the region as wholly Archean, and divides the rocks into two parts—a lower one, the Laurentian, and an upper one, the Ontarian, further subdivided into the Couchiching and the Keewatin. The term Laurentian is used here in a petrographic sense, to denote a series of entirely crystalline, generally acid, rocks, especially coarse grained gneisses and granites, in spite of the fact that these rocks have an eruptive contact with the overlying series, and so are later in age than the Ontarian.

The Couchiching rocks, found chiefly in the southern portion of the region along the boundary of Minnesota, consist in general of monotonous gray or brown mica-schists and gneisses, sedimentary in origin.

The Keewatin, which overlies the Couchiching where the latter is present and in other cases rests on the Laurentian, is largely composed of eruptives and their products—schists resulting from shearing, ash rocks, and agglomerates—basic in the lower part, acid in the upper.*

Lawson does not definitely correlate the Couchiching with either the Laurentian or Huronian, but Van Hise includes at least part of it in the Basement Complex.† Lawson puts the Keewatin doubtfully with the Huronian, pointing out numerous differences between it and the original Huronian as described by Logan. In general, however, Canadian geologists do not hesitate to class these altered eruptives and the accompanying sedimentary rocks as Huronian, and this usage will be followed in the present paper.

In the first place the Huronian clastics will be briefly described, and afterwards the relations subsisting between the series of rocks and their causes will be discussed. The term Archean will be used to include both Laurentian and Huronian (or Ontarian), though according to the classification adopted by the United States Geological Survey the latter would be included in the Algonkian.

Huronian Clastics

GENERAL STATEMENT AS TO ORIGIN

As to origin, the Archean clastic rocks of western Ontario are of three kinds—pyroclastics, autoclastics, and sedimentary rocks proper.

The pyroclastics, consisting of agglomerates, ash rocks, etcetera, are of

* Geol. Survey of Canada, 1887, p. 22, F, etc.
† Principles of pre-Cambrian Geology, p. 782.

great extent and importance, but have no special bearing on the subjects of this paper, and so need no extended description. It is probable that some rocks mapped as agglomerates are really autoclastic, especially those including fragments sharply angular in form and all of the same kind. These angular blocks of rock could hardly have been hurled into the air as bombs. Lawson mentions transitions between agglomerates and true conglomerates with waterworn pebbles, which might readily occur where volcanic materials drop into the sea.

The autoclastics are not very extensive and will merely be mentioned. They are produced by the action of crushing and shearing forces in rocks above the level where pressure produces plasticity, and so give a hint as to the original depth of the rock beneath the surface. The best examples known to me, omitting the eruptives already mentioned, are the limestone breccias of Steep Rock lake and certain conglomerates to be seen a mile west of Fort Frances, where in the sharp folding of thin beds of sandstone between layers of schist the latter has yielded plastically, while the former was broken to fragments now embedded as pebbles in the schist.

The ordinary clastics, true sediments, are of special interest as giving clear ideas of the conditions of the time, and so will be described more at length than the two previous groups. The Keewatin, though very largely of eruptive origin, contains important sedimentary members, and the Couchiching is wholly sedimentary.

KEEWATIN ROCKS

The water-formed clastics of the Keewatin are of great variety, including limestones, slates, quartzites, grits, graywackes, breccias, and pebble and boulder conglomerates. The limestones are, however, of limited extent, being found in any thickness only at Steep Rock lake, 70 miles east of Rainy lake, where there is a small area differing both petrographically and structurally from the rest of the region. These limestones have a very modern look, being scarcely at all crystalline in appearance, having cherty layers in gray limestone at some points and black, very carbonaceous beds at others. One almost expects to discover fossils in them, but none have been found. They have been folded in an extraordinary way into an anticline and syncline having their axis inclined 60 or more degrees.*

The slates are widespread, passing often into phyllites. Many of them contain carbonaceous matter, and some examples have a graphitic look and soil the fingers. One of them, from an analysis by Dr Adams, was

* H. L. Smyth: Geology of Steep Rock lake. Am. Jour. Sci., vol. xlii, 1891, pp. 317-331.

found to contain 7.44 per cent of carbon, and is porous as though hydrocarbons had volatilized leaving round cavities.*

These carbonaceous slates may be compared with the black slate of the Sudbury region, in which Dr Ellis has found 6.8 per cent of carbon, and which was at one time bituminous, as shown in Balfour township by a large vein of anthraxolite, once no doubt a fluid or plastic petroleum product.†

The widespread graywackes need only be mentioned, since they present no points of special interest, and the same may be said of the somewhat unusual quartzites and grits, but the conglomerates are of more importance. They are found in many localities, but only one example will be taken for description, that of Shoal lake, more thoroughly studied than the others because occurring close to a number of gold-bearing veins.

As seen on the shore of the lake, it is a schist-conglomerate consisting of green chlorite as a matrix, with well rounded pebbles of all sizes up to two feet in diameter embedded in it. That this portion of the conglomerate has undergone shearing is shown by the flattening and even tailing out of some of the softer pebbles and the breaking and shifting of the parts of some of the harder ones. The commonest rock species in the pebbles are quartz-porphyry and porphyrite, felsite, and green schists indistinguishable from adjoining Keewatin schists. In addition, there are fragments of black and red quartzite and of white, pulverulent sandstone, of vein quartz and of anorthosite. No gneiss or granite has been found after careful search, though some quartz-porphyries having the crystals of felspar and dihexahedra of quartz much crowded, look, at first glance, very like granite. Most of these pebbles are easily matched by Keewatin rocks, sometimes, however, many miles distant; a few are evidently Couchiching, and none are Laurentian. One rock, a quartz-porphyry, half made up of beautiful spherulites having feathery intergrowths of quartz and felspar, has not hitherto been recognized in Ontario.

Two or three miles north of Shoal lake and some distance across the strike the rock becomes much less schistose, has a coarse grit as matrix, and might almost be described as a breccia, since many of the pebbles are scarcely rounded. The pebbles are, however, of the same rock species as those on the shore of the lake.

This band of conglomerate is at least 16 miles long and 2 miles wide. Its thickness can hardly be less than a mile and may be almost double that, since the dip is steep, but a covering of sand prevents very accurate measurements of the width. A very similar conglomerate appears on the east shore of Upper Manitou lake, 50 miles to the north, containing por-

* Geol. Survey of Canada, 1885, pp. 58, 124, and 150, CC.
† Ontario Bureau of Mines Report, 1896, p. 159, etcetera.

phyry, felsite, quartzite, etcetera, and a fine example is found at Rat Portage, the matrix in this case, however, being sericitic instead of chloritic. Numerous other instances are found in various parts of the region. No pebbles which are undoubtedly Laurentian have been reported from any of them, though granite boulders are found, as, for example, near Abrams rapids, north of lake Minnetakie. They resemble closely eruptive granites piercing the Keewatin in neighboring localities, and differ in appearance from the characteristic granite of the Laurentian.

COUCHICHING ROCKS

The Couchiching rocks are all formed of sand or clayey sand more or less metamorphosed. The least changed were found by the writer on the shore of Rainy river a mile below Fort Frances and at the Scramble mine near Rat Portage. They form thin beds of yellowish or brownish soft sandstone lying between micaceous and chloritic schists. Under the microscope, beside grains of quartz there are particles of magnetite and numerous small prisms, probably of tremolite. In general, however, the Couchiching consists of biotite schist or gneiss, the quartz showing a clastic origin. Some of these schists contain sillimanite; more rarely they appear as thoroughly crystalline gneiss containing muscovite, microcline, etcetera, resembling the adjoining Laurentian and forming transitions toward it.

The Couchiching includes no coarse clastics and is nowhere separated from the underlying Laurentian by a basal conglomerate. These rocks have been mapped by Lawson, Smith, and McInness as covering extensive areas in the southern part of the region. Rocks of a similar kind occur on Manitou lake, near the lake of the Woods and at other points, but have not been separated in the mapping.

Relation of Keewatin to Couchiching

Lawson suggests that the Shoal Lake and other conglomerates represent the base of the Keewatin, and so indicate an unconformity between the Keewatin and the Couchiching;* but the finding of many Keewatin pebbles in the conglomerates opposes this view. A striking evidence that the break represented by these conglomerates comes high up in the Keewatin instead of at its base just above the Couchiching is to be found at Shoal lake, where a few boulders of coarse-grained anorthosite found in the schist conglomerate are exactly like portions of a boss of anorthosite two miles away. As this anorthosite area contains masses and strips of characteristic Keewatin schist swept off during its eruption, it is evident

* Geol. Survey of Canada, 1887, p. 84, F.

that an immense lapse of time separates the conglomerate and the underlying Keewatin, long enough for a coarse-grained plutonic rock to solidify, probably at considerable depths, and then for the region to be so profoundly eroded as to provide pebbles of the plutonic rock on a seashore. It is probable that the Keewatin conglomerates which have been referred to represent an important interval of erosion, perhaps equivalent to the one shown to exist by Van Hise and others between the upper and lower Huronian in the states to the south.*

Nevertheless the striking difference in the character of the rocks of the two series, wholly sandy sediments in the Couchiching, largely diabase and porphyry and the products of their alteration in the Keewatin, shows that conditions had greatly changed before the later series was formed.

It must not be assumed, of course, that all of the eruptives found in the Keewatin were surface flows of the same age as the enclosing rocks. Many of them are probably of the nature of laccolitic sills like the trap sheets in the Animikie near Thunder bay. In fact, but for the undoubted pyroclastic rocks among the sediments one might suspect that most of them were injected between the sedimentary beds, perhaps at a much later date, since no amygdaloidal varieties have been found. In a region where there has been so much folding and shearing it is rash to make positive statements on such matters, however.

Thickness of the Huronian Series

Lawson estimates the thickness of the Keewatin at about 5 miles,† and of the Couchiching at about the same;‡ but W. H. C. Smith suggests for the latter that there may be a number of closely appressed folds not easily separated, so that the thickness of the Couchiching may be very much less, though still reaching 8,000 or 9,000 feet.§

Following Lawson's estimate, the two series together sum up to 50,000 or more feet in thickness, though it is probable that the lowest beds of the Couchiching have been dissolved by the molten Laurentian rocks beneath, since no basal conglomerate has been found; and also that there has been a considerable amount of compression during the squeezing undergone in the sharp synclinal folds, as proved by the flattening of soft pebbles in the conglomerates.

The Couchiching, containing some little consolidated sandstones, can scarcely be included in the Laurentian; and as it forms transitions to

* Journal of Geology, vol. i, No. 2, p. 120.
† Geol. Survey of Canada, 1887, p. 55, F.
‡ Ibid., pp. 101 and 102, F.
§ Ibid., 1890–'91, pp. 54 and 55, G.

rocks recognized as Keewatin, and lies conformably, so far as observed, beneath the latter, there seems no reason why the two together should not be classed as Huronian.

The Huronian of western Ontario presents, then, an immense series of shallow-water sediments, in the upper part mixed with eruptives, perhaps largely later injections, but partly pyroclastic; the whole equal in magnitude to the thick series of clastics found in the preparatory troughs of great mountain ranges, such as the Appalachians and the Rockies.

Field Relations of Laurentian and Huronian

The field relations of the Laurentian, Couchiching, and Keewatin have been so admirably shown by Lawson that only a brief summary will be required here. He was struck by the fact that the lower Archean "occurs in large, isolated, central areas more or less completely surrounded by the schists of the upper Archean, the encircling belts anastomosing and forming a continuous meshwork."*

An examination of the Rainy Lake region, where the innumerable bare shores of islands and promontories give an unsurpassed exposure of the Archean, shows that the Laurentian consists chiefly of coarse reddish, often porphyritic rock, usually granite in the central part of the area, but showing foliation toward the margin where it comes in contact with the Huronian. The foliation of the gneiss is generally parallel to that of the schist beside it. Before the actual contact is reached one generally sees strips and fragments of the Huronian embedded in the gneiss, sometimes sharply angular, at others with softened outlines. Often the actual line of contact is hard to define, so mixed are the gneiss and the schist. Dikes of granite, pegmatite, or felsite generally run from the gneiss into the Huronian. Where the latter is Keewatin one usually finds it hardened into hornblende-schist instead of the more common chlorite-schist. The Couchiching rarely shows much contact metamorphism, though occasionally garnets and staurolites are developed.

The Huronian schists have almost always a steep dip away from the gneiss, seldom less than 45 degrees and often vertical, and are folded into sharp synclines.

The areas of Laurentian are of all dimensions from a mile or less in diameter to a width of 50 miles or perhaps even more, and are usually rounded in form. Good examples of the larger Laurentian areas are found in the one including the north arm of Rainy lake, nearly 50 miles long from east to west and 25 wide; and in the Grande Presqu'ile of the lake of the Woods, 30 miles in length from east to west and 18 in width.

* Geol, Survey of Canada, 1887, p. 142, F.

Of the smaller areas mention may be made of Sultana island a few miles from Rat Portage, famous for its gold mine. Here a boss of coarse porphyritic granitoid gneiss a mile in length by half a mile in width presents the same eruptive contact with the green Keewatin rocks as one finds around the larger masses. Another similar boss of coarse Laurentian granite was found by the writer at Caribou lake, east of the lower end of lake Manitou, the area being only about a square mile. Examples of intermediate sizes may be found on the Canadian Geological Survey's maps of the region.

Finer grained granites, generally showing no foliation on the edges of the areas, are common also both in Huronian strips and in the Laurentian; and many more small knobs and bosses than were mapped by Lawson in his somewhat hurried work will be found from time to time; such as the area of protogine containing so many gold-bearing veins at

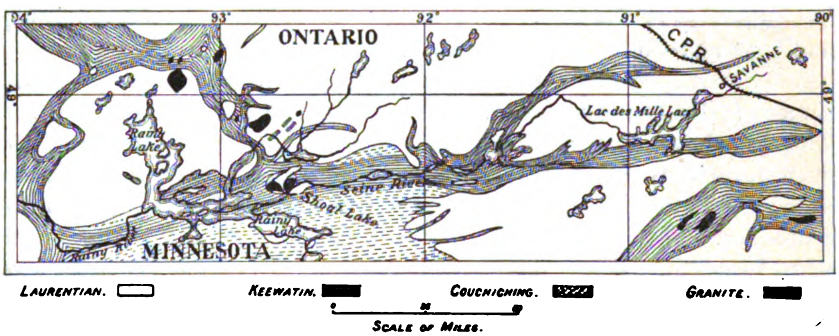

FIGURE 1.—*Geological Map of Part of Western Ontario.*

Shoal lake. So far as known, these granite bosses are later than both Keewatin and Laurentian, having penetrated both. It is, however, not always easy to say whether a given rock is Laurentian or a later granite, and it is likely that the two are connected in origin and might be arranged as a consecutive series. Both Laurentian and other granites send off felsitic dikes into the adjoining rock, and in this way one may often discover the proximity of a gneiss or granite area a quarter of a mile before reaching the contact.

It is worthy of note, as observed by Lawson, that often the gneiss grows darker and more basic near the contact with basic Huronian rocks, as though some of the latter material had been incorporated in the underlying Laurentian.

The accompanying map, figure 1, will illustrate the geological relationships just mentioned. It has been pantographed from three map sheets issued by the Canadian Geological Survey—the Rainy Lake, Seine River, and Shebandowan sheets—the work of Lawson, McInnis, and Smith. As the scale is small and the lake and river systems are complicated, it seemed wise to omit much of the topography so as not to confuse the geological boundaries. The portion mapped includes on its western side one of the most characteristic batholitic areas, though tracts to the north and west would serve equally well as illustrations if the geological sheets covering them had been published.

Only a few of the granite bosses are mapped, many being too small to be conveniently shown.

Sections through pre-Cambrian Mountains

Evidently this well glaciated Archean peneplain presents a most instructive section through the base of an ancient group of mountains. The sharp synclines of Couchiching and Keewatin nipped in between areas of gneiss and granite are merely remnants preserved because of their protected position. Often unfinished curves may be seen running out into the Laurentian, erosion having eaten below the bottom of the part that has vanished. Imagining these roughly circular or oval synclinal folds complete, we should see convex surfaces forming domes of diameters varying from 1 mile to 50 miles. What their height was in their prime one can hardly guess; but from their diameter and the steep dip of their synclinal portions one may suppose that the largest of these pre-Cambrian mountains were comparable with the greatest mountains of the present day.

The process by which they were built seems to have differed from that of later times in the earth's history, since they were not constructed of a series of parallel anticlinal folds, but were pushed up more like the laccolitic mountains described by Gilbert and Whitman Cross from the western United States, though with the difference that the up-pushing mass of molten rock was broad based.

While the larger areas of gneiss and granite are evidently batholites, some of the smaller granite bosses may be stumps of old volcanoes, though they could not have furnished the acid pyroclastics of the Keewatin through which they rise. Lawson looks on the Shoal Lake anorthosite boss as the stump of a volcano furnishing basic pyroclastics.*

Geological History of the Region

Reviewing the facts presented by the rocks of western Ontario, we find an oldest series, the Couchiching, consisting of sands and clayey sands

* Geol. Survey of Canada, 1887, p. 57, F.

deposited on a sea bottom, since entirely destroyed. The adjoining land must have presented an abundance of quartz-bearing rocks to furnish so many cubic miles of sand.

After at least a mile and a half and probably five miles thickness of these sands had been laid down in the southern portion of the region, the second or Keewatin series began, in which great eruptions of basic and acid rocks alternate with clays, grits, and conglomerates, the latter sometimes a mile thick. It is probable that an important break in the series is shown by the conglomerates. During the later part, if not the whole, of the time we may suppose that organisms existed, furnishing the large percentage of carbon found in some of the rocks.

Ultimately the sinking sea bottom was loaded with an eight or ten miles thickness of sediments and eruptive materials, as in the geosynclines preparing the way for later mountain ranges, and the slowly rising isogeotherms softened or fused the foundation, which rose into domes, the inner parts solidifying as granite, the outer more viscid portions having their constituents dragged into rough parallelism with the adjoining solid rocks and forming gneiss.

Comparison with other Regions

The usual theory of mountain-building, by lateral thrust due to the sinking in of the earth's crust to conform to the shrinkage of the interior through loss of heat or of volatile constituents, seems capable of producing only folds; and it is doubtful if thrusts in two directions at right angles to each other could produce anything except more complex forms of the same kind. The formation of irregularly placed domes demands some other cause.

One naturally compares these batholitic* mountains with the laccolites so distinctly brought before the world by Gilbert in his description of the Henry mountains of Colorado. There also there are oval domes, though not over 3 or 4 miles in diameter. Larger but more irregular ones are described by Whitman Cross from the adjoining western states. It is evident, however, that these cake-like masses of eruptive rock resting on their undisturbed floor of stratified rock differ greatly from the Rainy Lake mountain stumps, which are only more elevated portions of the general substratum of gneiss on which the sedimentary rocks now rest.

The eruptive masses described by Dawson from the Sweet Grass hills of northern Montana, tilting up "the previously horizontal beds of the plains," so that those immediately surrounding the igneous masses rest

* Bathylite is the form of the word preferred by Dana and Zirkel.

at very high angles,* seem more nearly related in general structure, and the same may perhaps be said of the extraordinary "plutonic plugs" described by I. C. Russell as pushing up the strata into domes in the Black hills of Dakota.† Probably some of the bosses of granite described in works on geology are of the same character, though many of them have a different relationship, pushing or fusing their way through overlying strata without becoming schistose themselves nor doming up the beds above.

The dome of the Black hills, as represented by Russell,‡ seems to come closest to the batholitic domes of western Ontario, though the section across the Black hills, copied from Newton and Gilbert, differs greatly from them in some points. As shown diagrammatically, the relatively small central plug of granite is surrounded by a wide band of vertical schist, on whose edges rests the dome of sedimentary rocks, as though there had been two upheavals, separated by a wide interval, during which the later sediments of the dome were deposited. The size of the Black Hills dome is greater than that of the west Ontario batholites studied up to the present, and the time of the latest uplift much more recent.

Cause of these Mountain Structures

Gilbert suggests for the laccolites that the ascending flow of molten rock rises only until the overlying rock is less dense than itself, when the latter is pushed up into a dome, the general law of hydrostatics being obeyed.§

Whitman Cross, following Dana, does not accept the hydrostatic theory, thinking that the force which set the lava in motion is sufficient to account for the facts.||

I. C. Russell suggests "that uplifts which owe their origin to the intrusion of a molten magma into the rocks beneath them be termed subtuberant mountains. They may be fancied to originate from the growth of a tuber within the earth's crust."¶ He thinks that the cooling and therefore contracting crust of the earth brings pressure to bear on the hotter interior, squeezing upward the molten rock, which may either form domes without reaching the surface or come to the surface forming volcanoes.**

* Geol. Survey of Canada, 1882-'83-'84, p. 17, C.
† Journal of Geology, vol. iv, no. 1, p. 23 etc.
‡ Journal of Geology, vol. iv, no. 2, p. 183, etcetera. I have been unable to obtain a copy of the "Geology of the Black Hills" in time for use in preparing this paper.
§ Geology of the Henry mountains, Washington, 1877, pp. 72 and 95.
|| Laccolitic mountain groups of Colorado, Utah, and Arizona-Washington, 1895, p. 241.
¶ Journal of Geology, vol. iv, no. 2, p. 189.
** Ibid., pp. 190, 191.

Suess thinks that eruptives of this sort cannot elevate the rocks above, but, on the contrary, can only occupy spaces already prepared by tensions in the earth's crust.*

Some of the methods referred to are obviously inapplicable to the batholitic type of mountains. Russell's suggestion of upwelling lavas urged by a squeezing action of the earth's crust can hardly be brought to bear on a region where the whole solid crust for thousands of square miles has been tossed into irregular domes. In fact it is difficult to see how any outside force can be applied in such a way as to elevate domes 50 miles across when the earth's crust adjoining is itself plastic. We seem forced to look for some force inherent in the masses themselves. If we look at the conditions we find that the granites of these batholites were probably fused hydrothermally, but not excessively hot, since blocks of basic Huronian rock, readily fused by a dry heat too low to melt granite, often lie in them with unrounded edges. Even at a relatively low fusion point they must have been much hotter and hence (potentially) lighter than the unfused rock above, particularly when the latter was basic like most members of the Keewatin series. This relatively light silicious magma, probably not thoroughly liquid, but only plastic, following the laws of hydrostatics crept upward where the load of overlying rock was smallest, the heavier Huronian beds meanwhile settling slowly into synclines between the rising batholites. The process may be conceived to have gone on very slowly under sufficient load to prevent violent disruptions of the overlying strata, since a certain plasticity of the beds is shown by the shearing observed, especially among the softer pebbles of the conglomerates.

The large porphyritic felspars observed in many of the gneisses and granites suggest two stages in the history of these rocks—an earlier one, before the ascent began, and the later slow consolidation. Augengneiss around the margin of batholites proves that the crystals existed before the shearing uprise was complete.

Some of the laccolites described by Gilbert show surprisingly perfect unbroken domes of stratified rock, and the same is true of the domes elevated by plutonic plugs; in both cases due, as suggested by Gilbert, to there having been load enough to prevent disruption. The amount of stretching undergone by the arched strata in the instances described was, however, not very great.

In the case of the larger batholitic domes of western Ontario the extension must have been as a rule much greater. The Grand Presqu'ile dome may have been comparatively low and flat, since a dip of only 24

* Antlitz der Erde, vol. 1, p. 218, etc.

degrees may be observed in Huronian schist resting on gneiss at the south of the batholite, and basic schistose rocks found in its interior west of Astron bay are perhaps remnants of the upper parts of the low arch of the dome.

In other cases where the dip of the schist is very steep or sometimes even tilted a little under the edge of the batholite, it is probable that the dome was much higher, and the stretching of the overlying strata must have amounted even to miles in large domes like that of Rainy lake.

Extent of the batholitic Region

The region whose geological history has just been sketched extends from the lake of the Woods on the west to lac des Mille Lacs on the east, a distance of more than 200 miles, with a width north of Rainy lake of 120 miles. Most of this large extent of country shows the mesh structure in a more or less typical way, though toward lac des Mille Lacs on the east the bands of Huronian tend to become parallel, suggesting an approach to the more normal folded mountain structure. Throughout this whole region the Laurentian has eruptive contacts with the Huronian, and nothing like a basal conglomerate of the Huronian can be found.*

It would be unwarranted perhaps to suggest that the relationships described are normal for the Archean, especially when relatively only a small portion of the immense extent of the Canadian Archean has been mapped with any detail, yet in a considerable number of instances similar relationships have been found.

Dowling maps imperfect mesh-like strips of Huronian about areas of eruptive gneiss and granite from the district of Keewatin † 80 miles north of the lake of the Woods, and Barlow states that the underlying gneiss has an eruptive contact with the Huronian in the Sudbury region 500 miles to the east of lac des Mille Lacs. Dr Bell, however, appears to differ from this view, explaining the relation of the two series of rocks, at Wahnapitae for instance, by assuming a fault.‡ My own observations near Sudbury and Wahnapitae convince me that at those points the contact is eruptive, since dikes of pegmatite, etcetera, may be seen passing

* Van Hise (Pre-Cambrian Geology, p. 786) follows Smyth in speaking of the Steep Rock Lake series as resting with a characteristic basal conglomerate on the eroded edges of the Basement Complex; but my own observations show this to be no exception to the general rule. The gneissoid granites which enclose the series form eruptive contacts with the Keewatin at the Harold Lake gold mine a few miles west of Steep Rock lake; and Smyth himself (Am. Jour. Sci., vol. xlii, 1891, p. 322) in describing the supposed basal conglomerate states that it contains large pebbles of quartz and greenstone, but mentions no gneiss or granite pebbles.

† Geol. Survey of Canada, 1894, part F.

‡ Ibid., 1890-'91, p. 14, F.

from the gneiss into the green Huronian rocks. The loops so characteristic of the Huronian farther west are, however, to be seen only indistinctly, if at all, on Bell's map of the region. Adams and Barlow show the same relationships between the Hastings and Grenville series of eastern Ontario and the underlying Ottawa gneiss,* and Adams maps similar curving bands of the Grenville crystalline limestones sinking into the gneisses below, in his report on the Laurentian area north of the island of Montreal.† These two series are probably the eastern equivalents of the western Huronian, the Grenville series having undergone a more intense metamorphism than the usual Huronian. The conglomerates found by Adams prove that these rocks were undoubtedly of sedimentary origin.

Still farther east, in the great Labrador peninsula, Lowe describes crystalline limestones and garnetiferous, graphitic gneisses forming bands in the Laurentian, though his evidence as to the relation of the ordinary Huronian to the underlying Laurentian is not so conclusive. He recognizes in some of the mica-gneisses sedimentary beds like Lawson's Rainy Lake Couchiching, but in other places speaks of Huronian rocks as resting unconformably on the Laurentian, though in some cases they are more or less interfolded with the Laurentian.‡

On the other hand, according to Van Hise, Logan's original Huronian, north of the lake from which it got its name, seems to be of later age than the underlying Laurentian, since he finds basal conglomerates or breccias containing fragments of Laurentian rock at two localities.§ Barlow, who has examined the same region, thinks, however, that there also the contact is eruptive.

From Van Hise's admirable "Principles of North American pre-Cambrian Geology" one finds that a conglomerate of the Huronian rests discordantly on the foliated edges of the Basal Complex at many points south of lake Superior,|| and Dr Dawson informs me that characteristic Huronian beds rest on an eroded Laurentian surface in New Brunswick.

It may be that at more southerly points the thickness of the Huronian series is considerably less than in the typical Archean region, and hence that the floor on which the sediments rested was not softened or fused, as happened farther north. On the other hand, it is not impossible that in the states south of the lakes rocks of a somewhat later age, resting on the upturned edges of the Archean (including the Rainy Lake Huronian) have been looked on as Huronian. Van Hise includes mica-schists, green

* Am. Jour. Sci., vol. iii, March 1897.

† Geol. Survey of Canada, 1895, part J.

‡ Geol. Survey of Canada, 1895, part L, p. 196, etc.

§ N. Am. Pre-Cambrian, 1896, p. 777.

|| Ibid., p. 784.

schists, etcetera, of Lawson in the Basement Complex, on whose eroded edges the Huronian is supposed to rest.* As it seems generally assumed that distinctly clastic rocks, such as the little altered Couchiching sandstone of Rainy river, should not be referred to the Laurentian, it might be well for a small party of American and Canadian geologists interested in these questions to go over certain typical regions together, so as to come to a common basis of classification for these difficult formations.

However it may be in other regions, there is certainly a very large area in northwest Ontario in which the relations between batholites of granite and gneiss and the schistose rocks of Huronian (Ontarian or Algonkian) age are as described in the foregoing paper. Tens of thousands, if not hundreds of thousands, of square miles of the western Huronian were once afloat on a plastic granitic magma which swelled into great bubble-like mounds, while the colder surface rocks tended to sink into the spaces between; and a phenomenon of such wide extent deserves careful study, whether the explanation given above be correct or not.

It is worthy of note that in several regions where ancient sediments were supposed to rest discordantly on the Fundamental Complex more detailed study has proved that the contact is eruptive. The latest instance is described by R. A. Daly, who finds batholitic gneiss pushing through overlying mica-schist in New Hampshire.†

It is probable that wherever sediments accumulate to a thickness of 40,000 or 50,000 feet the beds on which they lie become plastic if not fused, shift their place to correspond to the load, and form eruptive contacts with the rocks above. As this has taken place beneath every great mountain range, perhaps aided by relief from pressure under anticlines, and is no doubt still taking place where preparations are being made for the great mountain chains of the future, a so-called Fundamental Complex is to be regarded, not as characteristic of great antiquity, but as resulting from a certain set of conditions which may exist at any age. The older mountain ranges, having been more deeply eroded, give an opportunity to study these gneissic and granitic cores, while in later ranges they are still buried out of sight. It is likely, however, that a basal section through our present mountain ranges would show long bands of gneiss and granite rather than approximately circular batholites, such as we find in western Ontario.

If the supposition just made be correct, areas of the Laurentian or Fundamental Complex do not represent the earth's *erstarrungskruste* but are merely portions of the earth's crust, of sedimentary or other origin, which have been buried deeply enough for hydrothermal fusion

* Pre-Cambrian Geology, p. 782.

† Journal of Geology, vol. v, no. 7, p. 694, etc.

and have afterward been disinterred by long continued denuding forces. Good examples of wide areas of granitoid rocks, merging at many points into gneiss and having an eruptive contact with the overlying rocks, are to be found, according to Dr Dawson, in the Coast ranges and Interior plateau of British Columbia,* but here the Basal Complex is of Jurassic age.

Concluding Observations

It will be observed that the term Laurentian has been employed in this paper as Lawson and other Canadian geologists are accustomed to employ it, in a petrographical and structural sense for crystalline gneissic or granitic rocks underlying the Huronian. That these rocks have consolidated at a later time than the Huronian is evident, and therefore they have not the position in time which Logan supposed when the name was given. It may be advisable to provide another designation for these widespread rocks, which occupy the same position structurally and are formed of practically the same materials as those to the south, whose attitude with reference to the Huronian corresponds to Logan's original Huronian.

How much of the 2,000,000 square miles of the Canadian Archean presents the same relationships as have been described in this paper, and how much shows the orthodox unconformity between Huronian and Laurentian can be determined only by careful field work. If the eruptive contact is the normal type and the Huronian which rests discordantly on the Laurentian turns out to be really later in age than Lawson's Ontarian, we must look on the Couchiching series as presenting the oldest known rocks. This would carry back the ordinary sedimentary deposit of sands and clays to the beginning of known geological time.

*Geol. Survey of Canada, 1886, part B, and 1894, part B.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 9, PP. 239-256, PL. 17 FEBRUARY 26, 1898

SYENITE-PORPHYRY DIKES IN THE NORTHERN ADIRONDACKS

BY H. P. CUSHING

(Read before the Society December 29, 1897)

CONTENTS

INTRODUCTION

While in the field in the northern Adirondacks during the past few years the writer has noted dikes from time to time which prove to possess considerable interest. At first they were correlated with the bostonites which cut the rocks along the shores of lake Champlain a few miles to the southeast.* Later, doubts crept in as to the correctness of this reference, due partly to certain differences in the rocks themselves which were found to be constant, and partly to the fact that the dikes under consideration were only found cutting the pre-Cambrian rocks and never the adjacent Potsdam sandstone, whereas the bostonites cut all the rocks of the district up to and including the Utica slate. In the case of the associated diabase dikes, which are very numerous, this peculiarity of distribution soon amounted to a demonstration of their pre-Cambrian age.† The more acid dikes under discussion, however, are by no means abundant, and have a more restricted distribution than the diabases, so far as present knowledge goes. An opinion that they were also of pre-Cambrian age was hesitatingly expressed in a report to Professor James Hall, transmitted a year ago, but not yet published. A fortunate discovery in the field the past summer demonstrates the correctness of that opinion and in so much expands our knowledge of the volcanic history of the Adirondack region.

Geologic Occurrence

So far as yet known, these rocks occur only in dikes. All traces of surface flows, if such occurred, have been removed by erosion. To venture an opinion as to the depth below the surface at which the present surface exposures were formed is an hazardous proceeding. Even the narrowest dikes are completely holocrystalline, yet the walls have always exerted a marked chilling influence, and the groundmass of even the largest dikes is rather fine grained. It is thought probable that the depth must be measured in hundreds of feet, but that it was by no means excessive.

The dikes vary in size from 1 foot to over 30 feet in width, and their walls have a near approach to verticality. In common with the diabases and the post-Utica dikes they have a prevailing east and west trend, ranging from north 55° east to south 75° east.

Geographic Distribution

The location of the known dikes is indicated on the accompanying map, figure 1, of Clinton county, New York, which shows them all with the exception of the large dike at Burke, Franklin county. They occur in greatest abundance on Rand hill, in Beekmantown and Altona townships. The hill is an outlier of pre-Cambrian rocks projecting above the

* Kemp and Marsters: Bull. 107, U. S. Geological Survey, pp. 18–23.
† H. P. Cushing: Trans. N. Y. Acad. Sci., vol. xv, pp. 248–252.

level of the Potsdam sandstone which surrounds it. Its summit attains an altitude of 1,500 feet, with the Potsdam reaching up to 1,300 feet on

Figure 1.—*Sketch Map of Clinton County, New York.*

Showing by heavy black line the Potsdam-pre-Cambrian boundary and location by numbers of the syenite-porphyry dikes.

its western flank. The area of pre-Cambrian rocks exposed is about 8 square miles, within which are found 8 out of the total number of 14 of these dikes now known. Here would seem to have been a center of the igneous activity which formed these dikes. The same is true of the accompanying diabases, the exhibition of them here being a very impressive one, as was long ago noted by Emmons.*

The remainder of the known dikes occur within a radius of less than 20 miles from Rand hill, the one at Burke alone excepted. The latter is the only one yet found by the writer in Franklin county, though he has been over two-thirds of it, nor have Professors Kemp and Smyth found them as yet in Essex and Saint Lawrence counties. The available evidence indicates for them a quite restricted distribution, much more so than is the case with the diabases which abound in Essex and Franklin counties as well as in Clinton, and which outnumber many times the porphyry dikes.

Geologic Age

In Ellenburgh township, Clinton county, are widespread exposures of a massive, basal conglomerate of Potsdam age. Its pebbles are mainly of quartz, derived from the quartz and pegmatite veins which abound in the gneisses of the vicinity. The matrix is of coarse sand, made up of quartz, orthoclase, and magnetite—in other words, of well disintegrated gneissic debris. These ledges furnished abundant material to the southwestwardly moving ice-sheet, and boulders are very common around lower Chateaugay lake, but a few miles away in that direction. Among these blocks two of unusual character were found by Professor A. C. Gill and the writer during the past summer. They are much coarser, show less water action, and consist of less thoroughly disintegrated material, fragments of gneiss and of dike rocks reaching several inches in diameter, embedded in finer material of the same sort.† Both of the boulders contained diabase pebbles ‡ and one of them showed two considerable masses of syenite-porphyry.§ It must be frankly admitted that no similar conglomerate has been seen in place in the district, but its Potsdam age is regarded as certain, because no other unmetamorphosed conglomerate exists in northern New York except that at the base of the Potsdam, because this boulder has evidently not traveled far from its parent ledge and is associated with numerous blocks of undoubted Potsdam conglomerate, whose outcrops are not far distant, and because it is precisely the kind of rock which one would *a priori* expect to be

* Nat. Hist. of New York, part iv, vol. ii, p. 25.

† See R. Pumpelly: Bull. Geol. Soc. Am., vol. 2, pp. 209-222. This evidently represents a rock formed from material only partially disintegrated, after the more completely broken down, overlying material had been removed from the old land surface by the waves of the encroaching Potsdam sea.

‡ Diabase pebbles have been found at several localities in Potsdam conglomerate in place.

§ This boulder lies near the house of Mr Martin Shutts in Bellmont township, Franklin county, half a mile west of lower Chateaugay lake. It is deeply embedded in the soil.

locally formed by a sea encroaching on an old and deeply disintegrated land surface as the Potsdam sea did. As therefore these dikes are only found cutting pre-Cambrian rocks and as they furnished material to the Potsdam formation they must be of pre-Potsdam age.

That they are younger than the pre-Cambrian gneisses and anorthosites which constitute the mass of the Adirondacks is shown by the fact that they are found cutting both; but these old rocks have suffered profound dynamic metamorphism of such a character as to indicate that the rocks now exposed at the surface were then deeply buried beneath rocks since eroded away. The greater part of this erosion took place before the deposition of the Potsdam sandstone. The dikes, however, are unmetamorphosed and apparently did not cool at any great depth. Between the date of the anorthosite intrusion and of the deposition of the Potsdam sandstone there was a great time gap, during which the Adirondack region was above sealevel. The dikes are thought to have been formed toward the latter part of this interval.

Literature

So far as the writer is aware, the only published reference to the rocks under discussion is in an article by A. S. Eakle, in which a dike, clearly pertaining to this group, is described from Upper Chateaugay lake.[*] The description, though short, is quite accurate, bringing out the difference between these rocks and the bostonites.[‡]

The writer has also referred to these rocks in a general way, calling them bostonites and orthoclase-syenite-porphyries, in two reports to Professor James Hall not yet published.

Materials composing the Dikes

Megascopical appearance

To the eye the rocks from the various dikes differ considerably. Nearly all of them show phenocrysts of feldspar, which may reach a length of one centimeter or even more, and which vary much in size and in abundance in the different dikes. In the case of two of the dikes they seem entirely lacking, while on the other hand they form in another case from 10 to 15 per cent of the rock. They are commonly of red color, but may

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* Am. Geologist, vol. xii, p 31.

† I am inclined to believe that Mr Eakle is in error in locating this dike on Indian point. He was possibly misinformed as to the name of the point on which he found it. Professor Gill and I, in company, searched Indian point carefully for this dike and were unable to discover it. On the other hand, the point is all cut up with branches of a large diabase dike of which Eakle makes no mention, though he describes two diabase dikes from the lake shore. This dike could by no possibility have escaped his attention had he been on Indian point.

become greenish, and in one dike are of a pronounced red-violet hue, a color which the thin-section shows to be due to hematite infiltration along the cleavage cracks. The other colors are the result of slight alteration or due to inclusions.

The narrower dikes are dense, hard rocks with pronounced conchoidal fracture and aphanitic appearance. The larger dikes are equally hard and firm but coarser, the holocrystalline character of the groundmass being at once apparent to the eye. Some are of red color, others much darker, gray to black, with often a greenish tinge when slightly altered. The narrow dikes are more commonly red and the wider ones dark, but exceptions occur in each case. In the largest dikes the grain is sufficiently coarse to permit both the feldspar and the biotite to show their own colors.

In the case of dike 9, porphyritic biotite is common as well as feldspar. This is, however, true of this dike alone.

MINERAL CONTENT AND STRUCTURE

Order of abundance.—Under the microscope these rocks are found to contain the following minerals, arranged in order of abundance: Microperthite, biotite, magnetite, specular hematite, hornblende, quartz, albite, orthoclase, microcline, apatite, and titanite, with secondary chlorite, calcite, muscovite, epidote, and hematite. Microperthite and chlorite are the only two minerals present in all the dikes.

Microperthite.—The feldspar phenocrysts found in most of the dikes occur either singly or in clumps or bunches variously intergrown and oriented with respect to one another. They invariably show twinning after the Carlsbad law. In habit they are quite diverse, but ordinarily are either rather stout prisms, with their greatest elongation parallel to the vertical axis, or are thin-tabular, parallel to the clinopinacoid. They are bounded by the planes P, M, T, l, and x. Their boundaries are rough and somewhat irregular, with the adjoining groundmass firmly attached, giving the impression of a slight corrosive action by the latter.

Carlsbad twinning is also universal in the groundmass feldspars. These are sometimes lath-shaped, sometimes of stout habit. They always constitute the greater part of the groundmass.

Nearly all the feldspar shows the minute intergrowth of two feldspar species to which the term microperthite is applied. The intergrowths are of a quite varied character, ranging from a regular spindle arrangement, to which the name is sometimes restricted, to an irregular patchy mottling. The more common arrangement is illustrated in plate 17, figure 1. An unusual method is shown in figure 2, there being two sets of albite lamellæ which cross one another, producing a mesh structure.

The two kinds of feldspar differ in strength of double refraction, and while one is untwinned the other frequently exhibits fine twinning lamellæ after the albite law, whose extinction angles (8 to 10 degrees) indicate albite, while the untwinned feldspar seems to be orthoclase. The chemical analyses bear out this interpretation. In different individuals there is considerable variation in the relative amounts of the two feldspars present, but on the whole the amounts are nearly equal. It is worthy of note that in individuals in which the albite predominates there is a tendency to idiomorphic boundaries against their neighbors in which there is no such preponderance.

The microperthitic structure of the feldspars is sufficiently coarse to be readily made out with low powers in all the slides.

A very slight amount of microcline is present in small anhedra in a few of the slides. In no case has it been observed to be microperthitic.

Undulatory extinction is shown by much of the feldspar, its cause being a matter of some uncertainty. There is no sign of cataclastic structure in any of the thin-sections, nor any other indication of mechanical deformation aside from the undulatory extinction, except that in a few individuals, which either consist largely of albite or else have long albite spindles, a slight bending of the crystal is apparent. As the large part of the feldspar has neither of these structures, by whose aid the bending is readily made out, it may be more prevalent than it seems to be and be the cause of the undulatory extinction; but it is difficult to see how crystal bending could occur after rock solidification and cooling had taken place without the production of cataclastic structure. The fact that undulatory extinction is usually a feature of that class of igneous rocks whose feldspar is microperthite or anorthoclase would seem to justify the query as to whether it might not be due to strains produced in cooling, caused by the peculiar make-up of the feldspar.

Most of the feldspar is crammed with minute, dark inclusions. With high powers many of these prove to be specks of hematite, the nature of the rest remaining uncertain. Considering the freshness of most of the feldspar it is difficult to understand how it could become so filled in every part with secondary material, and the inclusions are therefore regarded as primary.

Biotite.—This mineral is the most prominent ferromagnesian silicate present, occurring in more or less amount in 8 of the dikes, and probably originally in 4 others where it has wholly gone to chlorite. In all but 4 dikes it is the sole dark silicate present. Though mainly confined to the groundmass, phenocrysts have been noted in two of the slides, and in others it occurs sparingly included in the porphyritic feldspars. It may therefore be fairly said to occur in two generations. It is, when fresh, ordinary deep brown biotite, with very small axial angle and the usual strong absorption. It is mostly somewhat altered and is sometimes completely gone to chlorite, magnetite forming at the same time.

In the 4 most acidic dikes ferromagnesian silicates are absent, except for a few minute shreds of chlorite present in the groundmass which probably represents altered biotite.

Hornblende.—This mineral occurs in 4 of the dikes, but in only 2 as the principal ferromagnesian silicate. It has an extinction angle of at least 12 degrees, and is strongly pleochroic in orange-brown and dark bluish green tones. It is so vaguely bounded and so altered as to prevent exact determinations or to give satisfactory interference figures, so its optical scheme is uncertain, though in character it seems like arfvedsonite.

Augite.—Eakle reports augite, almost completely altered, in the dike he describes. No mineral that can be decisively referred to augite occurs in my slides, but 2 of the dikes show a few grains of a gray-lilac mineral which is thought to be titaniferous augite, and a third shows granular epidote which may have resulted from the alteration of augite. A little undoubted titanite occurs in one slide.

Quartz.—In most of the dikes quartz is present, and in about half of them in considerable amount, constituting from 3 to 15 per cent of the rock. It only occurs in the groundmass and is wholly allotriomorphic. The more granitic dikes have a miarolitic tendency, and contain some minute quartz and clear orthoclase which seem secondary, but in no case is the amount great.

Iron oxides.—All the dikes contain either magnetite or specular hematite, commonly with sharply idiomorphic boundaries. Their amount is greatest in the more acid dikes and decreases as the ferromagnesian silicates increase; the specular iron occurs in the former rather than the latter. Its non-magnetic character and red streak leave no doubt of its nature.

Considerable secondary magnetite (from biotite) and hematite stain are found in many instances.

Pyrite.—Pyrite is sparingly present, in rather large idiomorphic crystals. It has been noted in two of the dikes and may occur in others.

Apatite.—All the dikes contain apatite in slight quantity in the usual minute needles, as inclusions in the other constituents. In dike 9 alone does it appear in any quantity. Here it is in larger, irregularly bounded fragments and forms an important item in the rock's make-up. Qualitative tests, after separation by Thoulet solution, give such strong reactions for chlorine as to make it doubtful if any fluorine is to be found in it.

Muscovite.—This mineral is present in small shreds in 2 of the more acidic of the dikes, in both cases accompanied by calcite which has often good idiomorphic boundaries. As the feldspars are quite fresh and dark silicates practically lacking, these minerals can not be alteration products of the rock itself, though the calcite certainly and the muscovite probably is secondary. Both the dikes have a miarolitic tendency, and these minerals have likely resulted from infiltration.

Groundmass structure.—While this varies much in the dikes it may be summed up in the one word, *trachytic*. Four main types are presented:

1. The structure is fluidal throughout, the lath-shaped feldspars having parallel arrangement and considerable interstitial quartz being present. This structure is limited to the more acid dikes, but only part of them possess it.

2. Flow structure is only apparent around the phenocrysts, otherwise the structure is like one of the following.

3. The structure is panidiomorphic granular, running into hypidiomorphic where the dark silicates become abundant. Even then these are largely included, and the majority of the contacts are of feldspar with feldspar. In all cases a few tabular, rudely idiomorphic feldspars occur, and may increase in abundance till they form most of the rock.

4. A trachytic structure, of stout, interpenetrating feldspar laths, with a slight amount of interstitial quartz and orthoclase.

FRESHNESS OF THE MATERIAL

Considering the proneness of rocks of this type to decay, surprisingly fresh material can be obtained from these dikes. The ferromagnesian silicates, to be sure, are often altered, but the feldspars are quite fresh in the majority of cases. The rocks are far less affected than are the much younger so-called bostonites of lake Champlain. This may be in part accounted for by the less compact character of the bostonites, which probably solidified at less depth, and by the less resistant character of the enclosing rocks, but the situation of the earlier dikes is mainly responsible for their present condition. They cut the low, outlying spurs of the Adirondacks, which felt the full force of glaciation and from which all material weakened by degradation must have been swept away. They also cut low, rounded, well polished exposures of the crystalline rocks. In nearly every case the postglacial weathering is but skin deep, it being seldom necessary to remove an inch of surface material from the joint blocks to obtain fresh rock. In many of the associated diabases even the olivine is found largely unaltered, while farther back in the mountains it is much more difficult to obtain such material.

SPECIFIC GRAVITY

The following table of the dikes* shows the specific gravity of each

*The numbers given the dikes are those applied in the field in the order of discovery and used in reporting to Professor Hall. The county has been used as the basis for numbering, but the great quantity of dikes renders the system cumbrous, and the township would be a better unit.

of them taken at 20 degrees centigrade, together with other characters.

No.	County.	Width.		Strike.	Wall rock.	Sp. gr.	Color.
		Ft.	*In.*				
28	Clinton..	7		S. 75° E..	Anorthosite.	2.604	Red.
25	" ..	6 –		E........	Gneiss	2.605	Grayish red.
29	" ..	1	10	N. 85° E.	Anorthosite.	2.621	Red.
107	" ..	5 +		(?)	Gneiss	2.627	Red.
31	" ..	1		N. 80° E.	Gneiss	2.654	Dark gray.
7	" ..	2	7	S. 80° E..	Anorthosite.	2.661	Dark red.
21	" ..	1	3	N. 80° E.	Gneiss	2.662	Red.
3	Franklin.	27	4+	N. 55° E.	Granite.....	2.663	Flesh color, spotted with black.
27	Clinton..	20 +		E........	Gneiss	2.673	Greenish gray. Red-violet phenocrysts.
103	" ..	3	9	S. 80° E..	Gneiss	2.689	Dark gray.
*	Franklin.	......	...	...	Gneiss	2.712	Dark greenish gray.
32	Clinton..	10 +		S. 80° E..	Gneiss	2.714	Grayish red.
95	" ..	30 +		N. 70° E.	Gneiss	2.716	Dark gray, reddish tinge.
9	" ..	10	3	N. 60° E.	Anorthosite.	2.766	Black, red spots.

The average specific gravity of the 14 specimens is 2.669. Numbers 28 and 107 are somewhat more altered than the rest, so that the results from them are probably too low. An inspection of the table shows that in general the wider dikes are heavier or more basic than those of slight width, though this is not universal and perhaps of no significance.

CHEMICAL COMPOSITION

Analyses

	I.	II.	III.	IV.	V.	VI.	VII.
SiO_2	63.02	68.96	52.53	67.16	65.66	62.28	63.20
Al_2O_3	14.87	15.25	18.31	14.53	20.05	19.17	17.45
Fe_2O_3	6.53	3.28	0.34	4.17	Trace.	3.39	3.60
FeO	....	....	6.43	....	Trace.	....	
MnO_2	0.46	0.23	0.15	....	0.13	....	....
CaO	1.12	0.76	3.15	1.26	0.67	1.44	1.40
MgO	0.95	0.20	1.82	0.41	0.18	Trace.	0.75
K_2O	5.62	5.01	6.47	6.10	6.98	5.93	5.88
Na_2O	5.85	5.45	7.26	5.55	6.56	5.37	6.90
P_2O_5	....	....	1.59	....	....	....	....
Cl	....	....	0.40	....	....	....	....
F	....	....	0.32	....	....	....	....
Loss	1.45	0.91	1.16	1.10	0.41	2.33	0.50
	99.87	100.05	99.93	100.28	100.64	99.85	99.68
O=Cl and F	....	....	0.22	....	....	....	....
			99.71				

*Specimen from one of the large pebbles in the boulder of Potsdam conglomerate. It was found in Franklin county, but the parent ledge is probably in Clinton.

I, II, and III. Dikes 27, 29, and 9 respectively, selected to represent the mean and the extremes of composition. Analyses by E. W. Morley.*

IV. Dike described by Eakle from Upper Chateaugay lake. *American Geologist*, July, 1893, page 31. Analysis by A. S. Eakle.

V. Keratophyr from Marblehead Neck, Massachusetts, described by J. H. Sears. *Bulletin Museum Comparative Zoology*, vol. xvi, no. 9, page 170. Analysis by T. M. Chatard.

VI. Bostonite from lake Champlain by Kemp and Marsters. *Bulletin United States Geological Survey*, no. 107, page 20. Analysis by J. F. Kemp.

VII. Nordmarkite (quartz-bearing syenite with low iron per cent) described by Brögger from north of Christiana at Tousenäs. Analysis by Forsberg.

Discussion.—Dike 29, column II, was selected as probably representing the most acidic of the dikes. The thin-section shows an unaltered rock composed of microperthite, quartz, and specular hematite, with such slight amounts of apatite and chlorite that they may safely be neglected. For purposes of calculation the slight amounts of manganese and magnesia are neglected.

Calculation of Analysis II

	Molecular ratio.	Orthoclase.	Albite.	Anorthite.	Quartz.	Hematite.
SiO_2	1149	318	528	18	285	....
Al_2O_3	150	53	88	9	....	....
Fe_2O_3	20	....	....	....	....	20
CaO	14	....	....	9	....	....
K_2O	53	53	....	....	....	....
Na_2O	88	....	88	....	....	....
	1474	424 29.49 %	704 46.09 %	36 2.48 %	285 17.11 %	20 3.28 %

Both apatite and calcite are present in slight amount—probably in sufficient quantity to account for the excess of lime, which amounts to only 0.27 per cent of the rock. The feldspar is seen to have the approximate composition, Or_2Ab_3, the plagioclase being albite, $Ab_{19}An_1$. The composition of the feldspar, recalculated to 100 per cent, will be as follows:

SiO_2	65.93
Al_2O_3	20.15
CaO	0.62
K_2O	6.37
Na_2O	6.93

which agrees well with the published analyses of microperthite and anorthoclase, except that in the latter the soda is often more in excess of

*The chemical analyses were made by Professor E. W. Morley, of Western Reserve University, whose hearty cooperation I gratefully acknowledge.

the potash. This of course represents only the average make-up of the feldspar. Different individuals unquestionably vary much in composition. The slight amount of magnesia in the rock is no doubt due to the little chlorite present. The quantity is so small as not to appreciably affect the calculation, which must give the composition of the feldspar within very slight limits. The constant presence of manganese in the analyses is of interest, though its source is purely a matter of conjecture.

It is impossible to make any precise calculation of analysis I on account of the decomposed condition of the hornblende and ignorance as to its composition. The rock is made up of microperthite, chloritized hornblende, magnetite, and quartz, with much hematite stain and a little apatite. The hornblende constitutes at least 10 per cent of the rock, and the excess of silica which has crystallized as quartz is between 5 and 10 per cent.

The rock of dike 9, analysis III, is quite abnormal, none of the other dikes being so basic. It consists essentially of feldspar, a portion of which is microperthite, biotite, and apatite, with a little magnetite. There is a little calcite and an exceedingly slight amount of what seems to be augite. The main difficulty in the way of a calculation arises from the uncertainty regarding the composition of the biotite, which has not been analyzed and which is abnormally rich in iron. The appended calculation is based on the assumption that it is a normal biotite of the composition $(SiO_4)_3\ Al_2\ (Mg, Fe)_2\ K_2$

Calculation of Analysis III

	Molecular ratio.	Apatite.	Biotite.	Magnetite.	Feldspar.	Residue.
SiO_2	875		198		656	21
Al_2O_3	180		66		114	
Fe_2O_3	2			2		
FeO	89		87	2		
CaO	56	37			7	12
Mg	45		45			
K_2O	69		66		3	
Na_2O	117				104	13
P_2O_5	11	11				
Cl	11	7				

All the ferrous oxide, with the exception of the slight amount necessary to form magnetite, and all of the magnesia, were assumed to be in the biotite and used as the basis for its calculation. The residue of alumina was then used as the datum for the feldspar calculation. The whole as it stands is very unsatisfactory, but the deficiency in alumina is likely to be explained by the fact that the assumed composition of the biotite departs considerably from its real composition. Biotites which are so rich in iron are notoriously variable in make-up. As it stands, the calculation indicates a rock composed of 33 per cent biotite, 60 per cent feldspar, 4 per cent apatite, and half a per cent of magnetite, and an inspection of the slides and the amounts obtained on separation by Thoulet solution closely corroborate this.

The presence of chlorine, the apparent excess of alkalies, and the close agreement in composition with some nepheline-syenites, which will be reverted to later. gave rise to the suspicion, which could not be confirmed, that sodalite and perhaps nepheline were present. No trace of gelatinous silica could be discovered either in treatment of the slides or of the finely powdered rock. Furthermore, careful qualitative tests of the apatite, after separation from all other ingredients of the rock, except a little biotite, which was entirely unaffected by the nitric acid employed, gave such strong reactions for chlorine as to justify the assumption that all or the larger part of the chlorine present was in that mineral, the fluorine shown in the analysis being probably present in the biotite.

The feldspar in this dike must be more largely constituted of albite than is the case in the other dikes. While part of the potash calculated in the biotite is no doubt replaced by soda, such part is not large in most biotites, and even at the best the amount of soda going into the feldspar must far exceed the potash. The testimony of the slides is not especially adverse to this. Considerable microperthite is present, but the larger part of the feldspar is not microperthitic; neither is it twinned. This untwinned feldspar, on separation, falls at 2.62, the specific gravity of albite, the microperthite being a little lighter, so that a fairly good separation of the two may be effected.

Petrologic Relationships

The magma which supplied the material forming these dikes was characterized by high percentages of alkalies, neither predominating, by very low lime and magnesia, rather low alumina, and proportionally high silica. The mineralogic peculiarities of the rock, paucity of ferromagnesian silicates, prominence of feldspar containing both alkalies, and quartz from the silica excess, depend directly on this chemical composition, and the rock has well marked chemic and mineralogic characters, which permit of no doubt as to its position. The group to which it belongs is intermediate between the syenite-trachyte and the elæolite-syenite-phonolite groups. With increasing lime and magnesia and decreasing alkalies comes a passage into the former with increasing alumina and decreasing silica into the latter. The following table permits of some interesting comparisons:

	I.	II.	III.	IV.	V.	VI.	VII.
SiO_2	63.02	64.63	60.03	59.70	54.61	52.53	50.36
Al_2O_3	14.87	18.15	20.76	18.85	22.07	18.31	19.34
Fe_2O_3	6.53	3.05	4.01	4.85	2.33	0.24	6.94 (with FeO)
FeO	....	....	0.75	....	2.50	6.43	
MnO	0.46	1.00	....	....	....	0.15	....
CaO	1.12	1.54	2.62	1.34	2.51	3.15	3.43
MgO	0.95	0.50	0.80	0.68	0.88	1.82	Undet.
K_2O	5.62	4.79	5.48	5 97	5.46	6.47	7.17
Na_2O	5.85	5.80	5.96	6.29	7.58	7.26	7.64
P_2O_5	....	....	....	....	0.15	1.59	....
Loss	1.45	1.08	0.59	1.88	1.13	1.16	3.51
	99.87	100.54	101.07	99.56	99.31	99.83	98.80

I. Dike 27, quoted from previous table.

II. Quartz-syenite from Fourche mountain, Arkansas, by J. F. Williams. *Arkansas Geological Survey*, 1890, vol. ii, page 99. Analysis by R. N. Brackett.

III. Pulaskite, Fourche mountain, Arkansas. *Op. cit.*, page 39. Analysis by R. N. Brackett.

IV. Elæolite-syenite, Fourche mountain, Arkansas. *Op. cit.*, page 81. Analysis by W. A. Noyes.

V. Elæolite-syenite, Caldas de Monchique, Portugal. *Neues Jahrbuch fur Mineralogie*, Beilageband iii, 1885, page 271. Analysis by Kaleszinsky.

VI. Dike 9, quoted from previous table.

VII. Elæolite-syenite, Beemerville, New Jersey, by Kemp. *Transactions of the New York Academy of Sciences*, vol. xi, page 67. Analysis by F. W. Love.

The Arkansas quartz-syenite can in all probability be regarded as a differentiation product from the elæolite-syenite magma. It differs from dike 27 (analyses I and II) mainly in its somewhat higher alumina. The pulaskite and elæolite-syenite (III and IV) are rather acid members of that group. Dike 32 of the Adirondack rocks has a silica percentage of 59.20, and though it has not been fully analyzed would probably yield results bearing the same relation to III and IV that I bears to II, namely, an equivalent silica percentage but lower alumina. A like result is obtained when VI is compared with V and VII, the former of which is regarded as a normal elæolite-syenite, while the latter is rather basic, as noted by Kemp. In these nephelite has formed abundantly, whereas there is no trace of it in the Adirondack rocks, so far as the writer has been able to detect. An interesting parallel range is shown by the two series, one of which is normally more acidic than the other, the two throughout differing principally only in the silica-alumina ratio.

An instructive instance is afforded of the considerable mineralogic contrast that two rocks may present, which seems out of all proportion to their chemical differences.

While the evidence is not perhaps demonstrative, it at least suggests strongly that these dikes are all differentiation products from a common magma. Their clustered distribution and mineralogic similarity, together with their regular chemical variation, make out a good case for this view; yet they range from 69 to 52 per cent of silica, from the acidity of granites to a basicity approaching that of basalts.

The striking cases of differentiation recently described by Brögger from Predazzo in the Tyrol and by Weed and Pirsson from Montana in quite similar rocks are at once called to mind. In the Bearpaw mountains, for example, Werd and Pirsson describe the differentiation of an augite-syenite magma into an exceedingly interesting series of gradational phases.* While the physical conditions under which rock solidification took place were quite different, the effects produced were so similar that the analyses are appended:

	I.	II.	III.	IV.
SiO_2	68.96	68.34	52.83	52.81
Al_2O_3	15.25	15.32	18.31	15.66
Fe_2O_3	3.28	1.90	0.84	3.06
FeO	....	0.84	6.43	4.76
MnO_2	0.23	0.07	0.15	Trace.
CaO	0.76	0.92	3.15	7.57
MgO	0.20	0.54	1.82	4.99
K_2O	5.01	5.62	6.47	4.84
Na_2O	5.45	5.45	7.26	3.60
P_2O_5	....	0.13	1.59	0.75
Cl	....	0.04	0.40	0.07
F	....	....	0.32	Trace.
Loss	0.91	0.45	1.16	1.09
	100.25	99.95	99.93	100.24

I. Dike 29, Clinton county, New York.

II. Quartz-syenite, Beaver Creek stock, Bearpaw mountains, Montana. Analysis by H. N. Stokes. *American Journal of Science*, May, 1896, page 354, analysis I.

III. Dike 9, Clinton county, New York.

IV. Mouzonite, Beaver creek, Bearpaw mountains. Analysis by H. N. Stokes. *American Journal of Science*, May, 1896, page 357, analysis I.

The Montana rocks show a still further differentiation to the more basic type, shonkinite. No similar rock has yet turned up in the Adirondacks, and there is strong probability that the Adirondack magma, before dif-

* Am. Jour. Sci., May, 1896, pp. 351–362.

ferentiation, was much more acidic than was that of Montana. The difference between III and IV consists simply in the higher lime and magnesia and lower alkalies of the Montana rock, producing pyroxene instead of biotite and andesite rather than albite. In I and II these differences have almost disappeared, yet are still sufficiently marked to have produced a little pyroxene in the one rock and a little biotite in the other.

The magma from which these rocks were produced belongs to the foyaitic type of Rosenbusch. At the one end the silica percentage is so high that the boundary between granites and syenites is reached, and the rocks might be called either alkali-granite or syenite-porphyries. The larger portion of the dikes are quite typical alkali-syenite-porphyries, nordmarkite and pulaskite types, the most basic being dikes 32 and 95, with 59.2 and 62 per cent of silica.* Between these and dike 9 is a wide gap, which it is probable will be filled by future discoveries. Dike 9 is rather basic to be classed as nordmarkite-porphyry. It recalls the minettes, with which it can not be united, owing to its deficient lime and magnesia and high alkali percentage. Its deep seated form would be a basic alkali-syenite, a rock not yet described, so far as the writer is aware. Brögger has described dikes of mica-syenite-porphyry from southern Norway, but unfortunately just now the writer has not access to his paper and does not know whether this basic phase appears or not. Rosenbusch mentions an occurrence from the Laurvik district,† characterized by considerable biotite and apatite and free from quartz, which may be close to this rock. We have here a basic alkali-syenite-porphyry, so basic as to make it very questionable whether it should be classed with the syenites at all.

General Conclusions

Kemp has shown that along lake Champlain acidic and basic dikes occur, which are younger than the Utica slate. Similar dikes occur about Montreal associated with nepheline-syenite, all younger than the Trenton limestone. At the recent Montreal meeting of the Geological Society of America Dr F. D. Adams stated evidence for their late Silurian and early Devonian age. Similar rocks are reported from many points in New England, associated sometimes with nepheline-syenite, but owing to the confused stratigraphy often without adequate determination of their age. To the westward in Canada, so far as the writer is aware, they are either lacking or have not yet been differentiated from the older eruptives.‡

* Determined by E. W. Morley.

† Mikroskopische Physiographie der Massigen Gesteine, p. 469.

‡ Conf. N. H. Winchell on "The latest eruptives of the Lake Superior region," Am. Geol., vol. xvi, pp. 269–274.

It has here been shown that acidic and basic dikes (syenite-porphyry and diabase) of pre-Potsdam age occur in the Adirondack region. Similar diabases, both as dikes and effusives, range widely to the east and west. The syenitic rocks are rarer, though also with a wide range. Taken together, they present a great similarity to the Keweenawan eruptives of the upper lake region, nor can they depart widely in age from them. Apparently the one region was depressed while the other was above sea-level, so that the clastics are lacking in the Adirondacks, but in both cases there is a similar relationship to an unconformable sandstone above and to a mass of gabbroic and granitic eruptives below.

Three distinct periods of igneous activity have been differentiated in the Adirondack region, leaving entirely out of the question the origin of the doubtful gneisses. The latest occurred probably in Silurian times and gave rise to the bostonites and basic dikes along lake Champlain. The porphyries and diabases preceded these in pre-Potsdam times. Still earlier are the gabbros and granites, whose precise relations to one another have not been determined, but which are both younger than all, or at least nearly all, of the gneisses of the region. Some of the gabbros were later than others, but there is no evidence of any special interval between them. In each of these three instances there is an association of basic and acidic rocks, and in each a close agreement in chemical composition, accompanied, however, by mineralogical and structural differences which are constant throughout the district.

Evidence is constantly accumulating to show that three similar periods of igneous activity were characteristic of the entire shoreline of the ancient Canadian and Appalachian protaxes. While much more evidence is requisite, interesting correlations are suggested, and are at least worthy of being borne in mind as working hypotheses.

Explanation of Plate

Plate 17.—*Thin-sections of Material from Syenite-porphyry Dikes*

Figure 1.—Intergrowth of orthoclase and albite shown in the center. Dike 25, × nicols, × 67.

Figure 2.—Portion of a large Carlsbad twin, occupying the entire field, showing intergrowth of albite and orthoclase, with two crossing sets of albite spindles, × nicols, × 85.

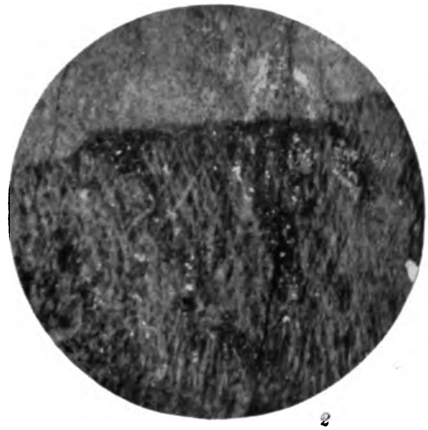
Figure 3.—Portion of large phenocryst from dike 3, showing intergrowth of same, × nicols, × 67.

Figure 4.—Flow structure, groundmass of dike 28, × nicols, × 67.

Figure 5.—Flow structure around phenocryst. Dike 27, × nicols, × 22.

Figure 6.—Thin-section of material from dike 31, with parallel nicols, to show the considerable amount of biotite and hornblende in the groundmass, feldspar white, biotite and hornblende (mainly the former) black. The white area to the right is a feldspar phenocryst, × nicols × 67.


1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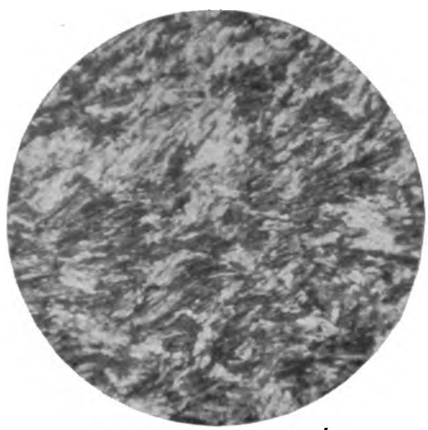
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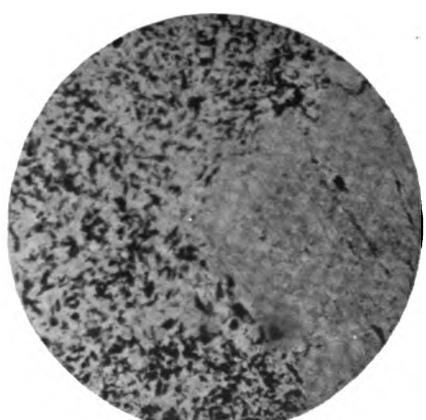
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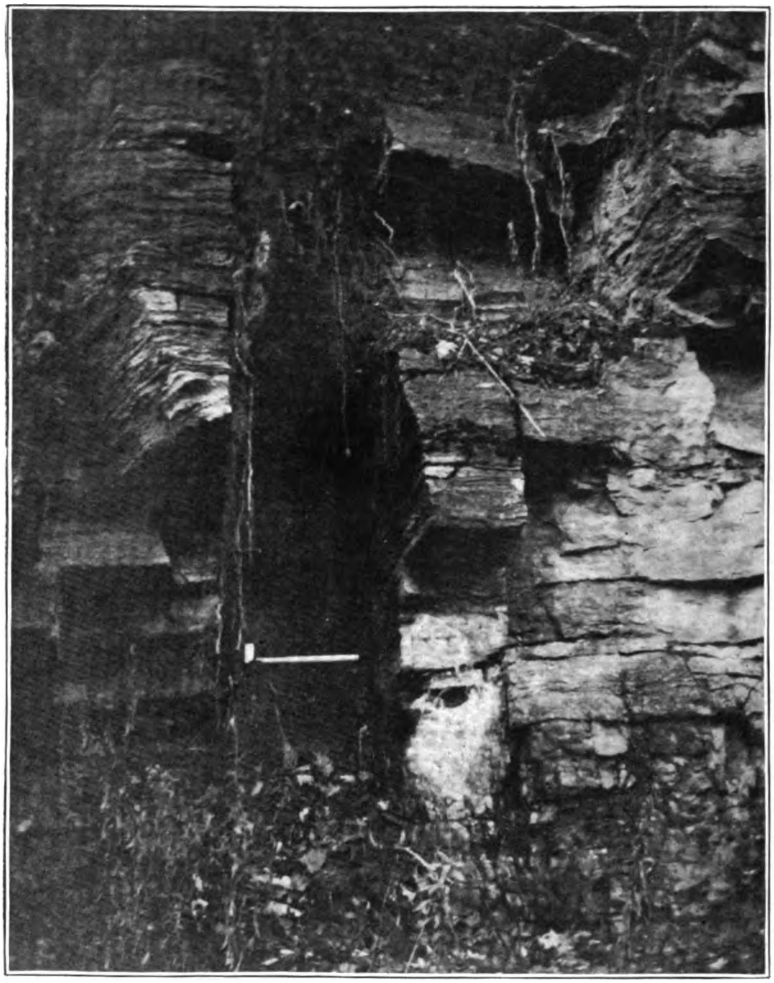
THIN-SECTIONS OF MATERIAL FROM SYENITE-PORPHERY DIKES



THE WEATHERED DIKE OF ALNOITE IN MANHEIM, NEW YORK

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 9, PP. 257-268, PL. 18. MARCH 28, 1898

WEATHERING OF ALNOITE IN MANHEIM, NEW YORK

BY C. H. SMYTH, JR.

(Presented before the Society December 29, 1897)

CONTENTS

INTRODUCTION

The importance of rock weathering is equally great, whether viewed from the purely scientific or from the economic standpoint.

As the initial step in the processes of subaerial denudation and subsequent deposition and in other relations, weathering demands the most serious consideration of geologists; while for a rational study of soils and of building stones, as well as for a thorough understanding of the conditions presented in the superficial portions of ore deposits, a knowledge of the principles of weathering is indispensable.

This is exemplified by, to cite only a few instances, such papers as those of Pumpelly,* Reade,† Chamberlin and Salisbury,‡ and Russell.§

* R. Pumpelly: The relation of secular rock-disintegration to loess, glacial drift, and rock basins. Am. Jour. Science (3), vol. xvii, p. 133. The relation of secular rock-disintegration to certain transitional crystalline schists. Bull. Geol. Soc. Am., vol. ii., p. 209.

† T. M. Reade: Chemical denudation in relation to geological time. Trans. Liverpool Geol. Ass., vol. iii., p. 211. Reprint, London, 1879.

‡ T. C. Chamberlin and R. D. Salisbury: Preliminary report on the driftless area of the upper Mississippi valley. Sixth Annual Report U. S. Geol. Survey, p. 199.

§ I. C. Russell: Subaerial decay of rocks. Bull. 52, U. S. Geol. Survey.

on the one hand, and of Shaler,* Hilgard,† and Penrose,‡ on the other. A decided impetus has recently been given to the study of weathering in general, both as to the processes involved and the results attained, by Dr G. P. Merrill's admirable series of papers, published in this Bulletin,§ and by his book, "A Treatise on Rocks, Rock Weathering, and Soils." || He has furnished numerous valuable data, together with the generalizations to which they lead, and has done much to establish a rational method for the study of problems in weathering.

In the following pages the writer presents the results of an investigation, largely based upon Merrill's methods, of an instance of weathering, which has especial interest in being well advanced, situated in a temperate climate, and apparently quite narrowly limited as to time.

Locality

The rock to be considered is exposed on both sides of the East Canada creek, which is the eastern boundary line of the town of Manheim, Herkimer county. The locality is of peculiar geological interest on account of the dikes present and the fault so beautifully exhibited; and it is quite familiar, the latter feature having been figured in at least three publications.¶ On the east bank of the creek three dikes are shown—one at the fault, another a few rods upstream, and the third two or three rods farther upstream. The latter dike is the largest of the three, having a width, with included horses of country rock, of about six feet. It was first exposed by blasting, done in connection with building operations some two years since, but now, unfortunately, is almost entirely covered.

On the west bank only one dike is shown. It is impossible to trace this across the stream to connect it with either of the dikes there, and the exposures on both sides are so limited that the trend of the dikes can not serve as a positive guide, but there can be no reasonable doubt that the dike on the west bank is the continuation of the large dike. The decrease in width to about thirty inches is due in part to the absence of horses of the wall rock, and in part to a variation in the width of the fissure.

Appearance of Rock in the Field

The varying character of the rock in the field has been briefly stated

* N. S. Shaler: The origin and nature of soils. Twelfth Annual Report U. S. Geol. Survey, p. 213.
† E. W. Hilgard: The relation of soil to climate. Bull. 3, U. S. Weather Bureau.
‡ R. A. F. Penrose, Jr.; The superficial alteration of ore deposits. Jour. of Geol., vol. ii, p. 288.
§ Vol. vi, pp. 321–332; vii, pp. 349–362; viii, pp. 157–168.
|| The Macmillan Company, New York, 1897.
¶ Geology of New York, pt. iii, p. 207.
Thirteenth Annual Report State Geologist of New York, i, plate facing p. 414.
W. B. Scott's Introduction to Geology, p. 247.

in a previous paper,* but, being of fundamental importance in the present inquiry, demands more extended consideration.

In the exposure on the east bank the rock is dark gray or nearly black, sometimes having a greenish tinge. The only mineral conspicuous to the unaided eye is a lustrous, dark-brown mica, in scales varying from minute up to half an inch or more in diameter. In certain sheared portions the rock is much altered, though retaining its deep color, with a rather more marked green tinge. Elsewhere it appears to be quite fresh, though surprisingly soft when hammered. This softness results from a change of some kind in the rock, which is further indicated by the presence of numerous veinlets of calcite in the form of "satin spar."

On the west bank the dike presents a totally different aspect. Instead of being nearly black in color, it is light yellowish brown, near the shade sometimes called golden brown. At the same time it is so thoroughly disintegrated that it may be easily scooped out with the hands. Indeed, so far as field evidence is concerned, there is nothing to indicate that the rock was once like that on the opposite bank except its occurrence as a clearly defined dike cutting the Calciferous "sand-rock" and the presence in it of occasional lumps of the parent rock and of abundant scales of mica, like those in the other rock, though considerably decomposed. But these very facts, which to a casual observer might appear of little moment, are quite sufficient, aside from the confirmatory evidence furnished by microscopic examination, to establish the essential identity of the two rocks.

The weathered dike, with a width of from 26 to 30 inches, is exposed vertically about 15 feet in the wall of the creek gorge (see plate 18), and to the bottom of the exposure the degree of weathering is quite uniform. There can hardly be a doubt that it extends to a greater depth; but while this, as well as the nature of the rock as it recedes from the vertical face, could probably be determined by a moderate amount of excavation, it would involve the destruction of a beautiful example of weathering in a region where such examples are rare. As it now stands, the exposure is terminated below by a heap of the weathered rock resting upon a shelf of Calciferous, partly produced by blasting. The refuse blocks and other detritus completely hide the downward continuation of the dike. The upper 15 feet of the "sand-rock" show the normal weathered surface of a calcareous rock, while the lower 10 feet have the fresh surface resulting from blasting.

The weathered dike has receded from the face of the cliff a distance of from two to five feet, and the fissure walls left exposed are weathered to

* Am. Jour. Sci. (4), vol. ii, pp. 290–292.

about the same degree as the upper walls of the gorge. To what extent the recession of the dike is due to natural causes and to what extent resulting from the quarrying operations it is impossible to say. The weathering of the walls can not be taken as indicating an early removal of the dike, as the weathering of both rocks would go on together, and excavation would doubtless show weathered walls extending as far as weathered dike-rock.

Though sufficiently coherent to stand with an overhanging face and to furnish by careful digging lumps several inches in diameter, the weathered rock has little of the toughness of a true clay, being readily crumbled in the hand, even while moist. Both in consistency and in size of grain the material is about midway between clay and sand, though if either term were to be applied to it the former rather than the latter would be used. Such material would fall an easy prey to the agents of erosion did not its occurrence as a dike prevent its removal. This mode of occurrence, moreover, has not only preserved the weathered rock for study, but has kept it in a state of almost ideal purity. Indeed, there seems to be but one way in which any superficial foreign mineral matter could find its way into the clay. The dike to the very bottom of the exposure is penetrated by abundant roots, sometimes as much as half an inch in diameter, and it is possible that on their death and decay channels might be formed through which soil would find its way into the dike. But as the soil immediately above the outcrop is hardly a foot thick, and is probably largely derived from the dike itself, the amount of impurity from this source can hardly be worthy of consideration.

It is entirely possible that mineral matter has been brought in from the wall rocks, but if so it would doubtless be as carbonates (and it is probable that the "satin spar" mentioned above is in part of this origin) and would not materially affect conclusions based upon the study of the rock. Thus the rock occurs in such a way as to fit it particularly well for an investigation of the effects of weathering upon it.

Petrography of the Rock

In the paper above referred to the petrographic character of the large dike has been described, and only a brief review is needed here.

The fresh rock consists largely of biotite and serpentine derived from original olivine, the latter mineral itself being extremely rare. The minor constituents are magnetite, apatite, and perofskite, together with secondary calcite. No melilite has been actually determined in the large dike; but as in all other respects the mineralogical composition is identical with that of the two other dikes, which are rich in melilite, it seems highly probable that melilite was originally present and has become obscured in the process of alteration. For this reason the rock is classed as alnoite, although the chemical composition, as shown below, is more like that of a peridotite; but as this is equally true of the alnoite at the fault,* the evidence is of little moment.

From the foregoing brief statement it is evident that the dike rock is far from being in its original condition; but, it is important to note, the changes which it has undergone are of the kind included under the head of alteration, the product of agents working at a considerable depth. Between such alteration and the more superficial process of weathering it is necessary to make a distinction, as Dr Merrill † has accentuated, although a sharp line of demarkation can seldom be drawn.

Samples of the weathered rock show under the microscope a very great preponderance of the mica. It has been somewhat bleached and irregularly stained with iron, but shows as a rule the normal optical properties in spite of the partial decomposition which it has manifestly undergone. The large scales are often pearly or iridescent, very soft and inelastic, sometimes closely resembling talc. Magnetite and perofskite are abundant, while apatite is probably present. A few very small crystals have the optical properties of pyroxene, but their exact determination is a matter of difficulty. The serpentine of the original rock is no longer perceptible and every trace of the calcite has disappeared. In addition to the determinable minerals, there is some very fine material of uncertain nature, but it is present only in small amount and is a less important factor than in most cases of extensive weathering.

Samples for Analysis

To determine the nature of the chemical changes involved in the weathering, both the fresh and the weathered rock were analyzed, with the results shown below. Of the fresh rock, a sample was selected that showed no calcite veins, although in thin section considerable interstitial calcite was evident, as is the case in every section of the rock examined.

The sample of weathered rock was taken at a depth of four feet from the surface of the ground, being three feet down in the fissure, measuring from the upper surface of the wall rock. This sample, while sufficiently near the surface to show nearly or quite the full extent to which the weathering has proceeded, was so protected within the walls as to be kept from any notable amount of foreign admixture, aside from

* Cf. Am. Jour. Sci. (3), vol. xliii, p. 325.

† A treatise on rocks, rock-weathering, and soils, p. 174.

organic matter. So far as possible, the latter was removed before proceeding with the analysis.

Results of Analyses

	I.	II.	III.	IV.	V.	VI.	VII.
	Fresh rock.	Weathered rock.	Fresh rock, calculated to total of 100.	Weathered rock, calculated to total of 100.	Loss for the whole rock.	Percentage of each constituent retained.	Percentage of each constituent lost.
SiO_2	35.25	33.10	35.51	33.40	9.69	72.69	27.31
TiO_2	2.25	2.90	2.27	2.93 }	0.00	100.00	0.00
Al_2O_3	6.10	7.88	6.14	7.95 }			
Fe_2O_3	8.53	16.71	8.59	16.86 }	0.55	96.30	3.70
FeO	5.60	1.48	5.64	1.49 }			
MgO	20.40	13.42	20.55	13.54	10.08	51.03	48.97
CaO	7.40	5.25	7.46	5.30	3.36	54.90	45.10
K_2O	2.88	0.29	2.90	0.29	2.68	7.73	92.27
Na_2O	0.70	0.23	0.71	0.23	0.53	25.03	74.97
Ignition	10.15	17.85	10.23	18.01	0.00	100.00	0.00
Total	99.26	99.11	100.00	100.00	26.89		

Discussion of Results of Analyses

A comparison of the results of the analyses of the two rocks, as they stand in columns I and II, brings out some points of interest. The figures for the weathered rock show a decrease in the percentage of all constituents aside from titanic oxide, alumina, iron oxide, and volatile matter. In the case of the latter, the figures do not indicate the true amount of change, for a separate examination shows the presence of nearly three per cent of CO_2 in the fresh rock, while there is not a trace of it in the weathered material. The latter, however, has about one per cent of organic matter to be taken into account; so it is evident that weathering has been attended by hydration, which has more than doubled the amount of water. At the same time, much of the iron has changed from the ferrous to the ferric condition, as would be inferred from the decided change of color in the rock. It is possible that the percentage of ferrous iron in the weathered material is less than stated in column II, as the organic matter present would tend to make the results high for this constituent.

The increase in the amount of alumina and iron oxide is in harmony with the general rule observed in cases of weathering under the normal oxidizing conditions.

In regard to the behavior of titanic oxide in weathering rocks, no very specific data are available, but from what is known of titanium minerals in general and from the insoluble nature of many artificial compounds of the element, a marked resistance to weathering might be expected.

This idea finds support in the work of Clarke * and of Dunnington.† In his table of the percentage composition of the earth's crust, based upon 880 analyses, Clarke gives 0.33 per cent as the estimated amount of titanium. This is equivalent to 0.55 per cent of the oxide. Dunnington has determined the titanic oxide in seventy-two soils of varied character, representing widely separated regions, and has found in them an average of 1.10 per cent of titanic oxide. While a comparison of these results does not furnish positive proof of the behavior of titanium minerals during weathering, it affords, in view of the character of the work in both cases, a strong indication that weathering produces a concentration of titanium. Lyons,‡ however, finds a large loss of titanium in the incipient weathering of some Hawaiian lavas; but as lime remained constant and magnesia actually increased, it would seem that there must be something unusual in the process, perhaps the action of sea water, as suggested by the author. In other cases, where the weathering is extreme, with a large loss of most constituents, he shows that titanium has suffered but slight decrease; and this is probably the more normal result.

In the case under consideration the titanic oxide has evidently been one of the most resistant constituents of the rock, its behavior being almost identical with that of alumina. Indeed, the ratio of increase for the two constituents is so nearly the same that if alumina be assumed as constant the titanic oxide has lost less than 0.3 per cent, an amount well within the limit of error of analysis. The relative increase of these two constituents is slightly greater than that of the iron oxide, and for this reason, together with their close agreement in ratio, the titanic oxide and alumina are assumed to have remained constant and are taken together as the basis for comparison of the two analyses.

Recalculating the analyses to totals of 100 and estimating the percentage loss of each constituent for the whole rock, the figures shown in columns III, IV, and V are obtained.

* F. W. Clarke: The relative abundance of the chemical elements. Bull. 78, U. S. G. S., pp. 34–42.

† F. P. Dunnington: Distribution of titanic oxide upon the surface of the earth. Am. Jour. Sci. (3), xli, pp. 491–495.

‡ A. B. Lyons: Chemical composition of Hawaiian soils and the rocks from which they have been derived. Am. Jour. Sci. (4), ii, pp. 421–429.

Of the abundant constituents, silica and magnesia have contributed almost equal quantities to the material carried away in solution. The iron oxide has yielded only a very small amount, differing but slightly from the assumptively insoluble titanic oxide and alumina. In view of the evident presence of considerable organic matter in the weathered dike, a decided amount of solution of the iron oxide might be looked for; and an irregular distribution of color in the weathered rock, as well as the staining of the mica, also points to this conclusion. Although this suggests the possibility that the figures for loss are too low, nevertheless oxygen has had ready access during the weathering, and oxidation has been a prominent feature of the process; so that it seems probable that the iron loss has not been enough greater than indicated by the figures to point to any serious error in the method of calculation—a conclusion sustained by the relation between titanic oxide and alumina. It is probable, as pointed out by Merrill, that in all cases where this method is employed the estimate of material lost is too low, rather than too high.

Of the less abundant constituents, lime has supplied only a moderate amount of material to solution, with potash not far behind it.

The total amount of material removed in solution, about 27 per cent, seems small in view of the very decided change in the physical character of the rock—a complete disintegration and marked change of color. Nevertheless, it is far in excess of the amount removed from some thoroughly disintegrated acid rocks;* and although in basic rocks physical and chemical changes keep closer together, the disintegration, while sufficient to destroy the coherence of the rock, has not reduced it to a fine clay, and is hardly to be considered excessive as compared with the amount of chemical change.

As to the completeness of the weathering, from the chemical point of view it can scarcely be thought that a rock containing 13 per cent of magnesia and 5 per cent of lime, and made up largely of readily recognizable minerals of greater or less complexity of composition, has reached a condition of stability under surface conditions. The composition is quite different from that of a typical residual clay, the ultimate product of weathering, and there can be no doubt that the process is far from complete.

The behavior of the weathered rock with solvents is suggestive in this connection. A sample was digested in very dilute hydrocloric acid upon the water bath for six hours, then for two hours with the acid diluted with only an equal volume of water. The residue was treated with sodium

* Cf. G. P. Merrill, Bull. Geol. Soc. Am., vol. vi, p. 324.

hydrate solution and subsequently weighed. It was found that 93.60 per cent of the rock had gone into solution.

It is evident that a rock so easily attacked by the strong reagents of the laboratory will, in the course of time, yield much material to the continued action of the weaker natural solvents, although of course some of the constituents easily dissolved by hydrocloric acid are nearly insoluble in natural reagents.

The fresh rock, under similar treatment, yields 93.45 per cent in solution. The close agreement of the figures in the two cases is a coincidence apparently of no particular significance, but it is peculiar that a rock of this character, after losing 27 per cent in solution, is still as readily attacked by solvents as before. According to the figures, indeed the weathered rock is slightly the more soluble; but this is probably due to the fact that the mica of the fresh rock is difficult to reduce to such a degree of fineness as to expose it thoroughly to the attack of the solvents.

Columns VI and VII show, respectively, the percentage saved and lost of each constituent, calculated again on the basis of titanic oxide and alumina remaining constant. Silica, which on account of its abundance gives a large figure for loss in the total rock, is seen to have yielded but 27 per cent of its original amount. The very slight loss of iron oxide is again made apparent, while, as would be expected, magnesia and lime have been removed in relatively large quantity. The excessive loss of magnesia as compared with lime is contrary to the general rule, but by no means remarkable, as Merrill * cites a much more extreme case in a basalt from Crouzet, France, where magnesia has lost 96.38 per cent and lime only 47.24; while in a diorite from Albemarle county, Virginia,† the loss is almost the same for both constituents.

By far the greatest loss has occurred in the alkalies, over 90 per cent of the potash having disappeared, while the soda has yielded not a great deal less. A considerable loss of the alkalies is the rule in weathering involving much chemical change, sometimes one, sometimes the other, being removed in larger proportion.

There is, then, presented in the case under consideration an example of weathering which has accomplished the thorough disintegration of the rock, with a loss of more than one-quarter of its original constituents, accompanied by oxidation and extensive hydration; but in spite of the great change in the nature of the rock, the composition of the residue is such as to indicate that the operation is far from complete.

* Bull. Geol. Soc. Am., vol. vii, p. 22, and Rocks, rock-weathering, and soils, p. 223.

† Rocks, rock-weathering, and soils, p. 225.

The chemical changes thus far effected agree closely in most respects with the phenomena generally observed in such cases, the only unusual features being the easy solubility of the weathered rock and the obliteration of the commonly stable alteration product, serpentine.

Contrast between Weathering and Alteration

In certain respects the contrast between weathering and alteration here presented is marked. The latter process led to the formation of much serpentine and calcite unaccompanied by any oxidation. Weathering has undone this work by removing both of these minerals, while at the same time oxidation has been extensive.

The only feature common to the two processes is hydration, whose effects are shown in both phases of the rock, although as a matter of fact the product of hydration by alteration has been destroyed during weathering; so even here, as well, the two operations are in a sense antagonistic. The alteration can hardly be regarded as a destructive process, while the weathering is eminently such.

Rate of Decomposition of Biotite

The general rule that biotite, though in acid rocks one of the first minerals to show signs of weathering, in basic rocks appears to be very resistant, finds excellent exemplification in this instance, as is evident from the foregoing. In the course of the investigation the question as to the proper interpretation of this rule has suggested itself. In the absence of any positive data as to differences in the weathering process or in the composition of the biotite in acid and in basic rocks sufficient to afford an explanation of the different rates of decomposition, the question has risen, Is this difference absolute or only relative? Or, in other words, does the biotite of a granite *actually* weather more rapidly than that of a basalt, or does it simply *seem* to weather more rapidly because the other constituents of the granite weather more slowly than do those of the basic rock? Without presuming to answer this question upon the meager and uncertain evidence of a single instance, the writer would simply point out the bearing upon it of the case in hand. Here is a rock weathered to a marked degree and yet containing abundant biotite, which, though much decomposed, is perfectly recognizable. It might be concluded at once that this comparative freshness of the biotite indicates a slow decomposition of the mineral due in some way to the fact that the rock is basic.

But in the Adirondacks, just to the north of this locality and in essentially the same climate, there are abundant acid rocks, in dikes and bosses, in a very fresh condition, although they have been exposed to weathering agents quite as long as the dike in question. The syenite dikes described by Professor H. P. Cushing in the present volume afford a concrete example, showing as they do only very slight evidence of weathering.

The conclusion is obvious that to reduce one of these acid rocks to the condition of the weathered alnoite will require a vastly longer period than has been needed in the case of the latter rock, and during all of that time the biotite of the acid rock will be undergoing decomposition. It follows that the decomposition of the biotite will go on almost simultaneously with the slow weathering of the acid rock as a whole, while it may lag far behind the much more rapid weathering of the basic rock, even though the actual rate of change in the biotite be the same in both cases.

That this is a true cause, though probably not the only cause, of apparent differences in the rate of weathering of biotite in acid and in basic rocks seems, at least, a justifiable hypothesis.

Time of Weathering

The position of the dike is such as to fix the period during which the weathering has been accomplished within narrow limits. As above stated, the dike is cut through by the narrow rock-walled gorge of the East Canada creek, which is assumed to be of unquestioned postglacial age. The weathered portion of the dike is on the convex side of a bend in the gorge precisely at the point that must have received the full force of the current in the early stages of the gorge-cutting. That the dike in its present condition could not resist this current for an hour, but would be scoured out as far as the weathering penetrates, is perfectly obvious, and the presence of the weathered material *in situ* is positive proof that it was not in its present condition when the upper part of the gorge was cut. On the contrary, it must have been nearly as tough and resistant as the surrounding "sand rock," or, in other words, in the unweathered condition shown on the east bank of the stream.

The very considerable degree of weathering here exhibited has been, then, accomplished in postglacial time; and this, too, in a temperate climate. Much stress has been laid upon the impetus given to weathering by tropical heat; but here is another instance to be added to those presented by Merrill * to prove the rapidity of weathering in cooler climates. It also tends to accentuate the fact that the nature of the rock is the most important element in determining the rate of weathering, although the precise character of the process may be largely influenced by climate.

* Bull. Geol. Soc. Am., vol. vii, pp. 359–361.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 9, PP. 269-328, PL. 19 MAY 19, 1898

METAMORPHISM OF ROCKS AND ROCK FLOWAGE*

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(Presented before the Society December 29, 1897)

CONTENTS

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INTRODUCTION

The following paper is adapted from a partly written treatise on the subject of metamorphism and the metamorphic rocks. In this article I shall summarize some of the more important physical and chemical principles which concern the alterations of rocks, and shall apply these principles to the alterations which occur in connection with dynamic action.

SUMMARY OF PHYSICO-CHEMICAL PRINCIPLES

The agents through which the alterations of rocks take place are water solutions and mineralizers. In the present discussion mineralizers will not be considered.

Below the level of the free surface of underground water the rocks are practically saturated; above that level the rocks are not ordinarily saturated, but upon the average contain a considerable amount of water held by adhesion between the liquid and the solid mineral particles. Both below and above the free surface water is the all-prevailing agent through which the chief alterations of rocks are accomplished.

The forces of metamorphism are (1) dynamic action, (2) heat, and (3) chemical action. In all of the various kinds of metamorphism ordinarily recognized in classifications, such as hydro-metamorphism, static metamorphism, pressure metamorphism, dynamic metamorphism, regional metamorphism, contact metamorphism, and thermo-metamorphism, all of the forces above mentioned are required, and also the agent, water. There is no metamorphism of a rock without the presence of water, and hence all metamorphism is partly hydro-metamorphism; there is no metamorphism of a rock without motion, either molecular or mass, and hence all metamorphism in an exact sense is partly dynamic; there is no metamorphism of a rock without the presence of heat, and hence all metamorphism is partly thermo-metamorphism; there is no metamorphism of a rock in which chemical action does not enter, and hence all metamorphism is partly chemical metamorphism. When it is realized that in all the varieties of metamorphism mentioned, chemical action, heat, and dynamic action enter as factors, only in different degrees, and when it is remembered that water is the universal agent which is present and active wherever metamorphism occurs, it is self-evident that the classifications ordinarily given are not satisfactory.

A critical examination of the classifications of metamorphism shows that the kinds of metamorphism recognized in the text-books are based upon the idea that the particular force or agent mentioned is dominant in the production of the particular metamorphism. However, they involve different factors, not belonging to the same category. For instance, thermo-metamorphism refers to heat; contact metamorphism refers to the contiguity of an igneous rock; hydro-metamorphism refers to the presence of water. As a matter of fact, all of the different kinds of metamorphism are related in the most intricate manner, and certain kinds of metamorphism which have been called thermo-metamorphism might just as well be called hydro-metamorphism.

Underground Flowage of Water

Underground water, the agent of metamorphism, needs to be considered from two points of view—(1) its movement and (2) its work.

(1) *MOVEMENT OF UNDERGROUND WATER*

The movements of underground waters are dependent upon (*a*) head, (*b*) the underground openings, and (*c*) viscosity.

(*a*) The flowage of underground waters is fundamentally caused by head. Head is due chiefly to the fact that the water, entering the ground at a certain level, after a longer or shorter underground course, issues at a lower level. Head also depends somewhat upon temperature. In so far as the water is warmer at its point of issuance than it was when it joined the zone of saturation, this is favorable to circulation, and gives an effect in the same direction as difference of elevation. This is due to the fact that the density of water varies inversely with the temperature. That the difference in density due to difference in temperature is sufficient to produce rapid circulation in pipes which are non-capillary is shown by the use of the principle in the hot-water system of heating of buildings. In such regions as the Yellowstone Park, and in fact any of the regions where igneous rocks have been lately intruded, the difference in temperature in the descending and ascending columns may be an important influence in the circulation. Underground circulation may be caused also by difference in temperature of the descending and ascending columns resulting from heat abstracted from the rocks due to depth alone.*

(*b*) Openings in rocks may be divided into (1) openings which are larger than those of capillary size, (2) capillary openings, and (3) subcapillary openings. For water, openings larger than capillary openings may be tubes which exceed .0508 centimeter in diameter, or may be sheet openings, such as those furnished by faults, joints, etcetera, the width of which exceeds .0254 centimeter. To movement of water in such openings the ordinary laws of hydrostatics apply. Capillary openings for water solutions include those which, if tubes, are smaller than .0508 centimeter in diameter, or, if sheet spaces, are narrower than .0254 centimeter, and which in either case are larger than the openings in which the molecular attractions of the solid material extend across the space. To the movement of water in openings such as these the laws of capillary flow apply. By subcapillary openings are meant those in which the attraction of the solid molecules extends from wall to wall. Such openings in the case of tubes are those smaller than .00002 centimeter in diameter, or, if sheet passages, are below .00001 centimeter in width.

Large openings are favorable to a somewhat direct course. This may be illustrated by the limestone regions, where there are numerous large joints and caves within which the water is quickly concentrated, and thus the underground course of the water is very largely in the upper part of the zone of fracture (see page 294). Small openings are favorable to a circuitous route. In order, for instance, to pass from one point to another, a wide range of openings must be used in order that considerable flowage shall occur. Large openings are favorable to rapid flowage; small openings are unfavorable to rapid flowage. This results from the rapid increase in resistance per unit volume with decrease in the size of the openings. In capillary tubes this resistance increases greatly with decrease of size, and in subcapillary openings the resistance is so great that the flowage practically ceases.

(*c*) The elements entering into viscosity are the concentration of the solutions and the temperature. The more concentrated the solutions, the greater the viscosity; but as the underground solutions of water are not strong, this is probably not an important element. The viscosity of water is inversely as the temperature, being only about one-fifth as much at 100° C. as at 0° C. Since the resistance to flowage of underground water is largely due to the internal friction of viscosity, it is seen that temperature is a factor of the greatest importance in its circulation. As the underground temperatures are 100° C. or more at comparatively mod-

*The sea mills of Cephalonia, by F. W. Crosby and W. O. Crosby: Technical Quarterly, vol. 9, 1896, pp. 6–23.

erate depths, a given head may there result in considerably greater flowage than at the temperatures prevailing at the surface. This is especially true of the capillary tubes, where the flowage is almost directly as the viscosity. In the capillary spaces it appears probable that with a given head flowage is five or more times as rapid at the temperatures which prevail in the lower part of the zone of fracture than in similar spaces near the surface. It is evident that this decrease of viscosity with increase of temperature is very favorable to the circulation of water in the deeper parts of the zone of fracture, for on account of it underground water upon the average follows a deeper path than it would were the viscosity everywhere the same. This may well be one of the chief causes which result in the rapid induration which seems to be characteristic of the lower part of the zone of fracture.

(2) *WORK OF UNDERGROUND WATER*

The potency of water as an agent through which metamorphism may take place is due, according to the modern ideas of physical chemistry, to its capacity to separate substances which it holds in solution into their free ions.* In this power of ionization it exceeds all other solvents. As the greater portion of underground solutions are rather dilute, at least where somewhat free circulation is the rule, we may suppose that the salts held in solution are largely separated into their ions, and therefore these free ions are ever ready for chemical reactions.

As illustrations of the above, we may take a few simple cases, as, for instance, solutions of NaCl, $MgSO_4$, HCl, KOH. In the dilute solutions which occur in nature these substances are not combined into salts, but are largely or wholly in the forms of ions—that is, if dilute solutions of the above-named salts are made, the substance in solution will be Na, Cl, Mg, SO_4, H, Cl, K, and OH.

Until recently it has been unknown how silicates behave when dissolved. However, Kahlenberg and Lincoln † have shown that the most important geological compound, silica, in dilute solutions occurs in the form of colloidal silicic acid. To illustrate: if a sufficiently dilute solution of sodium silicate be made, but which may be much more concentrated than ordinarily occurs in underground waters, the compound breaks up into the ions Na, OH, and colloidal silicic acid—that is, the two former are ionized but the silicic acid is not. From this fact it would not be expected that silicic acid is a chemically active compound, and

* The statements on this and subsequent pages concerning the principles of physical chemistry are mainly taken from the works of Ostwald and Nernst.

† Solutions of silicates of the alkalies, by L. Kahlenberg and A. T. Lincoln: Journ. Phys. Chem., vol. ii, 1898, pp. 88–90.

such is the case near the surface of the earth, at ordinary temperatures and pressures. However, upon subsequent pages it will be seen that at considerable depth, where the pressure and temperature are much above the normal, silicic acid is a most active compound. It may therefore be conjectured that when experiments are performed upon this acid under similar conditions it may be found to become partially ionized.

As material passes into solution it changes from the solid to the gaseous form, and consequently absorbs energy. However, where there is a lessening of the volume of the solution, as compared with the volume of the solvent and salt together, the molecules are brought closer together and energy is developed. Whether there is a rise or fall of temperature of the solution will depend upon the relative values of these factors. In general, the decrease in the volume of the solvent and salt in forming the solution is the more important factor, and there is a rise in temperature. However, in the case in which energy is used up in changing the salt from the state of a solid to that of a gas, and at the same time the volume of the solution is greater than that of the solvent and salt, energy is absorbed in both transformations, and then there is a marked absorption of heat or fall in temperature, as in the case of the solution of ammonium chloride.

When a solid is in a saturated solution the amount of the solid neither increases nor decreases; but, if pressure and temperature remain constant, it does not follow that no interchange takes place between the dissolved and solid salt. The kinetic theory of solutions leads to the conclusion that many molecules are released from the crystals into the solution, and pass from the solution into the crystals, but these amounts balance.

In order that crystals shall grow during the metamorphism of rocks, it is necessary that the solutions shall be saturated or supersaturated at the immediate place of crystal growth. As underground there is always a superabundance of material present as compared with the amount of water, we may suppose that at a moderate depth below the surface, and especially in the smaller spaces, where movement is slow, the solutions are often saturated. It is a well known fact that under conditions of saturation, with a superabundance of material, the larger crystals grow at the expense of the smaller ones, and that this process goes on more rapidly in proportion as the temperature is high and the pressure is great. This principle is taken advantage of in the chemical laboratory in the production of a coarse precipitate, before filtration, by boiling or other means, the finer particles of the precipitate being dissolved and the coarser being enlarged at their cost. The growth of the large crystals at the expense of the small ones is due to the fact that the smaller crystals are somewhat more soluble than the larger. The explanation of this change, as given by Ostwald,* lies in the "surface tension which exists on the boundary surfaces between solids and liquids, as on those between liquids and gases—the so-called free surfaces of liquids. This tension acts so that the surfaces in question are reduced in size, with the consequent enlargement of individual crystals (the total amount of precipitate remaining practically unaltered), *i. e.*, with the coarsening of the grains." During the change for a given volume the lessening of the total surface of the crystals, and consequently the lessening of the surface tension, results from the fact that the surfaces of the crystals will be small in proportion as the individuals are large. For a given volume of a substance the surfaces of the crystals are inversely as their diameters (see page 296). The increase in the size of the crystals lessening the surface tension may therefore be considered as liberating energy, and hence a reaction under this general law of change.

FORCES OF METAMORPHISM

The work of underground water is accomplished by the forces of mechanical action, heat, and chemical action.

DYNAMIC ACTION

No changes in rocks take place without movements of materials, small or great, for short or long distances. Wherever there is rearrangement of the elements, there must be movements; even in the case of a mineral passing from one form to an allotropic form, there is movement of the molecules.

Mechanical action assists water in its work by producing in substances a state of strain which may pass to the stage of pulverization (see pages 296–305). Moreover, dynamic action produces effects through chemical forces and heat and by the agency of water. The more important laws of the relations between pressure and chemical action are as follows: "If we compress a chemical system at constant temperature, there follows a displacement of the equilibrium in that direction which is associated with a diminution of volume. . . . Thus the solubility of a salt in water, *e. g.*, will increase with the pressure, provided that the dissolving is associated with a contraction of the solution plus the salt, and, conversely, the solubility will decrease if the separation of the salt (from the solution) is associated with a diminution of the volume of the system."† The first of these cases is that applicable to underground water solutions. "Moreover, those chemical forces are strengthened by compression, which condition a diminution of volume; and those chemical

* Foundations of analytical chemistry, by W. Ostwald: London and New York, p. 22.
† Theoretical chemistry, by W. Nernst: London and New York, 1895, p. 567.

forces are weakened by compression which condition an increase in volume." *

HEAT

All metamorphism takes place through the assistance of heat. Nowhere upon the surface of the earth, nor within the earth, is the temperature absolute zero. The activity of the molecules, or their kinetic energy, increases in proportion to the heat, and the chemical activity may be enormously increased by a slight increase in kinetic energy of the molecules. The temperature is therefore a most important factor in the rapidity of the changes of all kinds.

For instance, the activity of water is greatly increased by rise of temperature. A slight rise of temperature may increase its rate of solution several fold, or out of all proportion to the absolute change in temperature. At temperatures above 100° C., and especially above 180° C., the activity of water may increase to an amazing degree (see pages 319, 320).

Heat for the alteration of rocks is derived (1) from deep within the earth by conduction, or by convection through water or magma, (2) from dynamic action, (3) from chemical action, and (4) from the sun.

CHEMICAL ACTION

No change takes place without chemical action. By chemical action is meant the taking of material into solution, the deposition of material from solution, the interchange between materials in solutions, the interchange between materials in solutions and adjacent solids, and, finally, possibly the interchange of the adjacent solid particles. I say possibly, for such an apparent interchange is probably accomplished through the medium of a separating film of water, in which case the apparently simple reaction is really accomplished by transfers between the solutions and solids. In all these interchanges, including those of simple solution and deposition, according to the modern ideas of physical chemistry, the salts are separated into their ions, and it is by the migration of these free ions that the interchanges are accomplished.

RELATIONS OF CHEMICAL ACTION, HEAT, AND PRESSURE

The more important laws expressing the relation of chemical reactions and heat are as follows: "If we heat a chemical system, at constant volume, then there occurs a displacement of the state of equilibrium, and in that direction toward which the reaction advances with absorption of heat."† "Those chemical forces which condition a development of heat, will always be weakened by an increase of temperature; and conversely, those which condition an absorption of heat will be strengthened by

* Nernst, loc. cit., p. 567.
† Nernst, loc. cit., p. 566.

such an increase in temperature; and it is this fact which, primarily, gives the preceding proposition its universal validity."* "If we heat the system therefore, the reaction which takes place will be accompanied by absorption of heat; if we cool the system, the corresponding reaction will develop heat."† "On the whole, the preponderating chemical reactions at lower temperatures are the combinings (associations) which take place with the development of heat: while the reactions preponderating at higher temperatures are the cleavings (dissociations) which take place with the absorption of heat."‡ This last is van't Hoff's law.

The meaning of this law may be illustrated by the following reactions: At ordinary temperatures CO combines with O, producing CO_2, with great liberation of heat; at very high temperatures CO_2 dissociates into CO and O, with very great absorption of heat. This illustration makes it clear that van't Hoff's law, as stated by Nernst, must replace that of Satz and Berthelot, that "every chemical change gives rise to the production of those substances which occasion the greatest development of heat."§ However, this rule, according to Nernst, usually agrees with experiment, and he concludes that, "other things being equal, there is the more chance that a substance can be formed, the greater its heat of condensation."||

"In general, in comparing substances which are chemically analogous, and soluble with difficulty, the heat of precipitation (= the negative value of the heat of solution) is greater the more insoluble the substance is."¶

Finally, the relations between heat, pressure, and chemical action in a solution may be generally expressed as follows: "Every change of one of the factors of an equilibrium occasions a rearrangement of the system in such a direction that the factor in question experiences a change in a sense which is contrasted with the original change."**

APPLICATION OF PHYSICO-CHEMICAL PRINCIPLES TO THE EARTH'S CRUST

It is evident from the foregoing principles that within the superficial zone of rocks in which reactions take place directly under our observation, and within the deeper-seated zone in which reactions have taken place and later have been brought within our observation, there may be

* Nernst, loc. cit., p. 566.
† Outlines of general chemistry, by W. Ostwald: London and New York, 2d ed., 1895, p. 312.
‡ Nernst, loc. cit., p. 583.
§ Loc. cit., p. 581.
|| Loc. cit., pp. 585, 586.
¶ Loc. cit., p. 504.
** Loc. cit., p. 567.

opposing tendencies. The changing factors in these two physico-chemical zones are temperature and pressure. Both of these increase with depth.

Upper physico-chemical Zone

The chemical reactions which occur within the upper zone of observation of the earth are at the lower temperatures referred to in van't Hoff's law. Hence near the surface the reactions usually, if not always, take place with the development of heat, according to the first part of van't Hoff's law. Therefore in this zone the occurrence of a reaction in the alteration of rocks is favorable to further reaction and alteration, for the heat developed by the first reaction is retained by the adjacent material, at least for a time, and this promotes a subsequent reaction, etcetera; but this tendency would be reversed if the temperature became too high. The pressure near the surface is small, and therefore the law of chemical reactions with the liberation of heat in the outer zone is the dominating factor.

Hence an alteration may take place which works with or against pressure. In the first case, both the chemical reaction and the compression in volume result in the liberation of heat; in the second case, the heat liberated is that developed by the chemical reaction minus that absorbed as a result of the work done in expanding the volume.

In the treatise from which this paper is taken it will be shown that the upper physico-chemical zone is divisible into two parts, the reactions within which strongly contrast: (1) an upper belt, mainly above the level of underground water, which is generally known as the belt of weathering, where disintegration, decomposition, and solution are the rule, and (2) a lower belt of greater thickness, in which cementation of openings is the rule, and therefore a belt in which induration is one of the most characteristic features.

The material dissolved in the upper belt is abundantly deposited in the lower belt, and thus there is a constant downward transfer of material. The total amount of material which has been deposited in the thick lower belt is only in small part derived from the thin belt of weathering which exists at a given time; but, as a result of erosion, the belt of weathering is constantly migrating downward and encroaching upon the upper part of the belt of induration, and therefore there is never lack of soluble material in the upper belt, which may be dissolved and transferred to the lower belt, where it may be deposited.

Lower physico-chemical Zone

If one imagines himself as passing from the surface to considerable depth below the surface, the temperature ever becomes higher, and consequently the temperature may become so high that the tendency for reactions to take place which result in the development of heat is less dominant. However, at moderate depth, under ordinary conditions, say at 9,000 meters, the temperature is not very high, probably in the neighborhood of 300° C. Thus the tendencies for reactions to take place under the first part of van't Hoff's law, rather than the second part, would generally still control for a very considerable depth if it were not for the enormous pressure. This may become the dominating factor, especially in places of mass dynamic action, and reactions take place which result in the production of less volume. The compression may be accomplished by the driving off of a substance, as water or carbon dioxide, by the replacement of one substance by another, as magnesium for calcium, or by the more regular arrangement or greater complexity of the molecules, as in the case of devitrification. All of these condensations result in the evolution of heat. If, in order to produce the condensation, the chemical reactions are of such a character as to occur under the second part of van't Hoff's law (and, as subsequently seen, this is commonly the case), they result in absorption of heat. The net result as to absorption or evolution of energy will depend upon the relative values of these opposite factors.

Relations of the two physico-chemical Zones

Where expansion of volume is the rule, energy is absorbed (1) in increasing the volume of the rock affected by the reaction, and (2) in lifting the overlying rock in order that space shall be available for the expansion. Where contraction of volume occurs, energy is developed (1) by the decrease in the volume of the rock affected by the reaction, and (2) by the sagging of the overlying material. Below the extreme outer film of the earth the second factor is of vastly greater importance than the first, and its relative importance increases with depth. This is more broadly true in the case of expansion than in the case of contraction. The importance of the second element in the case of expansion is illustrated by the frequent rapid hydration or slacking with great expansion and rapid disintegration which follows when a partly hydrated rock, buried but a few feet, is brought to the surface.* Apparently, when in place, the tendency for hydration and development of heat was not sufficient to lift the superjacent material. When this necessity was removed by relieving the material from pressure, the process went on to completion with great rapidity. In the case of contraction in the zone of fracture, the strength of the rocks may be sufficient to prevent subsidence

* Disintegration of the granitic rocks of the District of Columbia, by G. P. Merrill: Bull. Geol. Soc. Am., vol. vi, 1895, p. 332.

and the filling of the spaces produced by the reaction. A common illustration of this is the vesicular dolomite; however, in the deep-seated zone of rock flowage the sagging occurs and energy under (2) is liberated.

I conclude from the foregoing that, in so far as energy is concerned, there are four cases: The chemical reaction may (1) release energy, and result in the development of heat; (2) may consume energy, and result in absorption of heat. The change of volume may be (3) by compression, and result in the development of heat, or (4) by expansion, and result in the absorption of heat. (1) and (3) will be called plus, and when they are combined the heat developed is equal to their sum; (2) and (4) will be called minus, and when they are combined the heat absorbed is equal to their sum. When (1) and (4) or (2) and (3) are combined, heat may be developed or absorbed, depending upon the relative values of the energy of the chemical reaction and that of the change of volume.

As a case in which the reactions as to temperature and pressure are each in opposite senses in the upper and lower physico-chemical zones may be mentioned hydration and dehydration. The first process occurs in the upper zone, and represents an association which takes place with the great development of heat, while the second process occurs in the lower zone, especially in connection with mass dynamic action (see pages 306–310), and represents a dissociation which takes place with important absorption of heat. The first process results in very considerable expansion of volume and absorption of heat; the second process results in equivalent contraction of volume and development of heat. Therefore in the upper zone the first part of van't Hoff's law of chemical reactions dominates, and in the lower zone the law of pressure controls.

The first part of this statement is sufficiently evident; the second possibly needs some explanation. To drive off the combined water of rocks at ordinary pressures usually requires a temperature above 110° C. This temperature under mass static conditions would be found at a depth of about 3,300 meters. It is certain that at depths less than this dehydration occurs (see page 309); hence I conclude that the increase of temperature does not produce the reaction. The volume of the hydrated solid is less than that of the residual solid plus the separated water; therefore, if the water could not escape, pressure would tend to preserve the combination. However, at any depth there is effective pressure tending to squeeze out both the free water between the particles and the combined water, as one may squeeze the water from a sponge. During the process the combined water gradually joins the escaping free water. This effective pressure is equal to the weight of the superjacent rocks, less the weight of an equal column of water. Thus if the rocks have a specific gravity of 2.7, the effective weight in producing dehydration and driving out the free water at a depth of 3,300 meters is that of a column of material of this height with specific gravity of 1.7. This would be the case under mass static conditions; under mass dynamic conditions, where the pressure as a result of thrust may be much greater than that due to weight, the effective pressure tending to separate the water would be much greater; consequently, under such conditions, dehydration may occur at much less depth than under mass static conditions (see pages 309, 310).

One or two minerals may be mentioned which illustrate the processes of hydration and dehydration in the two physico-chemical zones. Near the surface and to a considerable depth, under mass static conditions, limonite and other hydrated oxides of iron develop. Deeper down, and especially in connection with mass dynamic action, hematite is frequently produced by dehydration of the hydrated oxide. As another instance may be mentioned the somewhat similar compounds, chlorite and biotite. Near the surface and under quiescent mass conditions chlorite forms. Deep below the surface, and especially under mass dynamic conditions, biotite ordinarily develops. This is nowhere better illustrated than in the Michigamme formation,* in the Marquette district of the Lake Superior region, where these two minerals directly replace each other under the law just stated.

A second important reaction separating the outer crust of the earth into two physico-chemical zones is the mutual replacement of oxygen and sulphur. In the upper zone oxygen replaces sulphur, and at the same time may largely oxidize that element. This results in great liberation of heat, and also in expansion of the volume of the solid compound. Oxidation may take place without replacing another element, as when iron protoxide is changed into iron sesquioxide with expansion of volume and liberation of heat.

In the lower zone sulphur replaces oxygen with condensation and with great absorption of heat. In the case of the most common replacement, that of the oxygen united with iron by sulphur, the absorption of heat is very great indeed, as is shown by the following reactions:

$$Fe + O + H_2O = Fe\ O_2H_2 + 683\ K.$$
$$Fe + S + nH_2O = FeS\ nH_2O + 238\ K.$$

K is the large calorie and is equal to 1,000 small calories. From these equations it is apparent that in the replacement of the O of FeO by S

* The Marquette iron-bearing district of Michigan, by C. R. Van Hise, W. S. Bayley, and H. L. Smyth: Mon. U. S. Geol. Survey, no. xxviii, 1897, pp. 452–459.

that the heat absorbed is more than 683 K — 238 K, or 345 K, for in the above equations a larger amount of water is combined with the FeS than with the FeO.*

Another set of reactions of the most fundamental importance and widespread character, in which the first part of van't Hoff's law of chemical reactions and the law of pressure stand opposed to each other, and which occur in an opposite sense in the two physico-chemical zones, is the mutual replacement of carbon dioxide and silicon dioxide. Near the surface carbon dioxide replaces silicon dioxide, with great development of heat and expansion. The general fact of the carbonation of the silicates under these conditions the world over is well known.

It is in the outer of the two belts of the upper physico-chemical zone, (see page 278) that of weathering, in which the process of carbonation goes on with greatest rapidity. Simultaneously with the deposition of the carbon dioxide much of the silica replaced is taken into solution and is carried downward by the percolating waters. In the inner of the two belts of the upper physico-chemical zone the silica is deposited upon an enormous scale. This deposition is probably accompanied by considerable absorption of heat, under the law that the negative value of the heat of solution is greater, the more insoluble the substance (see page 277).

Of course, carbonation in the upper zone may take place without replacing some other compound, as in the case of the union of carbon dioxide with iron protoxide of magnetite, thus producing iron carbonate; but in this case the liberation of heat and expansion in volume are even greater than in the replacement of silica by carbon dioxide.

In the lower physico-chemical zone, and especially under mass dynamic conditions, silica replaces carbon dioxide upon the most extensive scale with great absorption of heat and with condensation. As illustrations of this may be mentioned the formation of wollastonite from pure limestone, of tremolite from dolomitic limestone, and of actinolite and grünerite from ankerite or from siderite. In the impure limestones under deep-seated conditions, where numerous bases are present, various complicated silicates form, such as other pyroxenes and amphiboles, and tourmaline, chondrodite, etcetera.

The physico-chemical principles cited (pages 275–277) give reasons for the existence of the above reverse sets of reactions in the two zones. We can now state a cause why hydration takes place in the first and dehydration in the second, and so on for other reactions characteristic of each of the physico-chemical zones. The depths at which the reactions reverse for different compounds and for the same compound under differ-

* Lehrbuch allgemeinen Chemie, von W. Ostwald: Zweiter Band, 1892, pp. 296, 301.

ent conditions are very variable. One of the most important of these variables is as to whether the conditions are mass static or mass dynamic.*

However, all reactions do not reverse in the two physico-chemical zones. The first part of van't Hoff's law of heat and the law of pressure may work together—that is, in both zones the reaction may occur which, simultaneously with the development of heat by chemical action, also results in development of heat by condensation. In so far as cases of this kind occur, it is to be presumed that such reactions are common to both zones. As an instance in which heat is probably evolved both by the chemical reactions and by the movements in both zones may be mentioned the devitrification of glass (see pages 289–291). The chemical reaction is presumably under the first part of van't Hoff's law, and the volume is decreased. A case of condensation is the replacement of calcium by magnesium in limestone, thus transforming the rock into dolomite.

Another illustration of reactions in the lower zone in which the first part of van't Hoff's law of chemical action and heat may coincide with the law of pressure and both result in the development of heat, is the production of the heavy compounds with complex molecules, such as garnet, staurolite, etcetera; also, in the lower physico-chemical zone decarbonation may take place without being replaced by silica, as in the case of the formation of magnetite from iron carbonate. This reaction is accompanied by partial oxidation. The decarbonation results in the absorption of heat, the oxidation develops heat to a greater degree; therefore the reaction is a case of the development of heat by chemical reaction and of heat by condensation, and thus the first part of the law of heat and the law of pressure work together.

The reactions above summarized but illustrate the fundamental difference between the two physico-chemical zones. In this paper other less important reactions, separating the outer crust of the earth into two zones and the upper zone into two belts, cannot be considered.

It is thought to be certain that the total of all the changes taking place in the whole of the mass of rocks concerned in any given movement result in the dissipation of energy, and it is believed that such is the fact for each of the physico-chemical zones separately. In the upper zone the chemical reactions result in plus (see page 280); the average volume reaction results in minus. It is, however, thought certain that the residual is plus. In the lower zone the average of the chemical reactions is

* The verification from authorities of the heat of the chemical reactions and the volume relations for the majority of the changes above mentioned have been very kindly made for me by Mr A. T. Lincoln. Mr Lincoln has found the results used either in the works of Thomson, Ostwald, Mendeléeff, or other standard authorities, or from the data there found has been able to calculate results which answer the specific questions I gave to him.

minus; the average of the volume reaction is plus. It has already been (pages 279, 280) seen that the amount of energy required for this volume change rapidly increases with depth, and in the lower zone it is thought that the plus resulting from the volume change is greater than the minus coming from the chemical reaction, and therefore that the residual is plus.

Hence we conclude that the changes which take place in each of the zones are under the general law of the running down of energy into the form of heat which is dissipated, and thus accords with the apparent rule of the universe.

As a corollary to the foregoing pages is the conclusion that in the upper zone, where pressure is relatively unimportant, upon the average, alterations result in the expansion of the volume of the rocks; and in the deeper seated zone, where pressure is important or dominant, upon the average the alterations result in the contraction of the volume of the rocks. It follows as a further conclusion from this that the tendency of the alterations in the first zone is, upon the average, to produce minerals of lower specific gravity than the original minerals, while in the deeper seated zone the tendency upon the average is to produce minerals of higher specific gravity.

As illustrating the first rule are the minerals produced by the disintegration and decomposition of rocks near the surface, out of which the sedimentary rocks are built. Some of these are kaolinite (G., 2.6–2.63), quartz (G., 2.65), calcite (G., 2.72), chlorite (G., 2.65–2.97), serpentine (G., 2.5–2.65), talc (G., 2.7–2.8), zeolite (G., 2–2.4), limonite (G., 3.5–3.96), etcetera. All of these minerals and the most of the other abundant undecomposed minerals, such as feldspar (G., 2.55–2.75), which make up great masses of sedimentary rocks, have comparatively low specific gravities.

The second rule is illustrated by the change from low to high specific gravity of the minerals, where the sedimentary rocks are metamorphosed. As just seen, the minerals which compose the unaltered sedimentary rocks are originally those of low specific gravity. Some of the abundant resultant minerals in the equivalent metamorphosed rocks have considerably higher specific gravities, as, for instance, muscovite (G., 2.76–3), biotite (G., 2.7–3.1), pyroxene (G., 3.2–3.6), and amphibole (G., 2.9–3.4), and the still heavier minerals, garnet (G., 3.15–4.3), staurolite (G., 3.65–3.75), chloritoid (G., 3.52–3.57), hematite (G., 4.9–5.3), and magnetite (G., 5.168–5.180). Less common heavy minerals are andalusite (G., 3.16–3.2), fibrolite (G., 3.23–3.24), and chondrodite (G., 3.118–3.24). With the above are the lighter minerals, quartz and feldspar; but even these are quite as heavy as the average of the original minerals.

It is noticeable that in the altered rocks in proportion as deep-seated metamorphism is advanced the heavier of the above minerals appear. In the early stages of the metamorphism of shales mica develops plentifully and the rocks become slates. If the metamorphism is more intense the heavier minerals, garnet and staurolite, appear, the material of the previously developed micas being absorbed at the places occupied by the garnet and staurolite.

The garnet, staurolite, chloritoid, andalusite, and tourmaline bearing mica-schists and mica-gneisses of the Penokee and Marquette districts of Michigan and the Black Hills of Dakota, produced by the alteration of clastic rocks, are perfect illustrations of the above changes.* In these rocks the acid feldspars (G., 2.55–2.67) have extensively altered into quartz (G., 2.65) and mica (G., 2.76–3.01) and therefore have passed into minerals denser on the average than those from which they were derived; also. the heavier minerals, garnet, etcetera, have developed on an extensive scale in the more metamorphosed varieties.

It is not supposed that there are not individual exceptions to each of the rules that in the upper physico-chemical zone lighter minerals form and in the lower zone heavier minerals develop. Indeed, exceptions are known to both. As illustrating such exceptions in the upper zone are the cases already mentioned (see page 283), the devitrification of glass and the replacement of calcium by magnesium. As a case in the lower zone of the change from higher to lower specific gravity is the alteration of pyroxene into amphibole. Upon the average the former is slightly heavier, and yet in the lower zone, both under mass static and mass dynamic conditions, pyroxene very generally alters to amphibole. Of course, in this transformation a change may simultaneously take place in the chemical composition (and this may have an effect upon the volume of the minerals); for, in general, pyroxene contains a greater proportion of calcium and less proportions of magnesium and iron than the amphiboles. However, this apparent exception to the rule of the production of compounds of high specific gravity in the lower zone may be only apparent, for in some of the deepest seated crystalline schists, pyroxene and not amphibole has developed, and it is suspected that sufficiently deep this is the rule. If this be the case, the real meaning of the reaction above considered is, in order that pressure shall become the dominating factor in the pyroxene-amphibole group, it must be very great.

However, whatever exceptions may be discovered in the cases of indi-

* The Penokee iron-bearing series of Michigan and Wisconsin, by R. D. Irving and C. R. Van Hise: Mon. U. S. Geol. Survey, no. xix, 1892, pp. 305–318. Mon. no. xxviii, cited, pp. 448–450, 452–454, 456–459. The pre-Cambrian rocks of the Black Hills, by C. R. Van Hise: Bull. Geol. Soc. Am., vol. i, 1890, pp. 222–229.

vidual minerals, the rules that in the upper physico-chemical zone the alterations upon the average result in expansion of volume and in the lower zone the alterations result in the contraction of volume are believed to hold and to be of fundamental importance in the metamorphism of rocks.

This principle of the development of minerals of high specific gravity at depth and of low specific gravity near the surface has a direct application to the crystallization of magmas. From a magma of a given chemical composition there can be little doubt that the greater the depth, and therefore the greater the pressure at which crystallization occurs, the higher the average specific gravity of the compounds which form, or, in other words, the greater the specific gravity of the rocks. However, in this paper no attempt will be made to work out the applications of the rule to individual minerals and rocks. Although other factors enter into the phenomena, the presence of glass in rocks which have crystallized from magmas at and near the surface, and the absence of glass and the presence of more dense, crystallized minerals in the deeper-seated rocks, is perhaps the most striking single illustration of the truth of the principle.*

METAMORPHISM FROM THE DYNAMIC POINT OF VIEW

From the foregoing summary it is evident that there are various lines of thought which a discussion might follow. In the treatment of the entire subject of metamorphism, from which the present paper is adapted, an attempt is made to follow several of them; but in the present paper I shall discuss certain phases of the subject of metamorphism from the point of view of dynamic action.

Dynamic action is of two kinds—molecular dynamic action and mass dynamic action. By molecular dynamic action is meant interchange between the molecules. Metamorphism by such interchange has generally been called static metamorphism. Molecular dynamic action is always accompanied in some degree by mass dynamic action. By mass dynamic action is meant deformation of the body of the rocks. To

* The above conclusion as to the condensation of material at considerable depths has an important bearing upon Reade's theory of mountain making. (The Origin of Mountain Ranges, by T. Mellard Reade: London, 1886.) His explanation of the rise of mountains is that the volume of the thick deposits of sediments increases as a consequence of the rise of the isogeotherms. I believe that possible expansion due to this cause is more than compensated in the case of the sediments by the mechanical bringing of the particles closer together as the result of pressure, in many instances to the practical disappearance of the interspaces, and by the condensation of the material itself by the physico-chemical changes above explained. The condensation also has a bearing upon estimates of crustal shortening. In so far as condensation occurs, shortening of the outer crust of the earth may allow accommodation to a nucleus of decreasing size without crustal corrugation.

alterations in connection with such deformation the term dynamic metamorphism is usually restricted. Mass dynamic action is always accompanied by molecular dynamic action. It is recognized that there are all gradations between molecular dynamic action and mass dynamic action. However, in many regions the phenomena are produced in connection mainly with one or the other.

Molecular dynamic Action

Molecular dynamic action involves various degrees of movements.

(1) Presumably the lesser movements are the cases of change in crystalline form and of strain within the elastic limit. In the change of a substance from one crystalline form to another—as, for instance, of aragonite to calcite—the movement of the molecules may not involve more than a redistribution or rearrangement of those which are adjacent. In the case of substances strained within the elastic limit the molecules are simply pressed slightly closer together or pulled slightly farther apart, and yet these very slight adjustments may have a most profound effect upon the physical properties of the materials. For instance, amorphous glass when strained but slightly and well within its elastic limit becomes an anisotropic substance. Leucite crystallizes in the isometric system at high temperatures. As the mineral cools it passes at once into an anisotropic form. The alteration from one form to the other may be seen by alternately heating and cooling this mineral under the microscope. In the foregoing cases, while we cannot doubt that movement occurs, the readjustment is molecular, and is therefore beyond the power of the microscope to determine its character.

(2) In a second class of movements there is a rearrangement of the chemical elements by which new compounds are produced from old compounds. Material may be added to or subtracted from a given mineral or from glass, or either minerals or glass may be altered into two or more other minerals, with the simultaneous addition or subtraction of material. The added material in any case may come from some other particle not far distant. The material subtracted in any given case may be added to another particle at a greater or less distance. Illustrating the above are the alterations of feldspar into muscovite and quartz, and olivine into serpentine and ferrite. The motions involved in these changes are confined within such short distances that the naked eye does not ordinarily discover the relations of the original and secondary minerals. Such movements are microscopic.

In such changes in the case of the dense rocks, in which there is little mass dynamic action, chemical analyses appear to show that the average composition of the rocks does not greatly change, except by hydration. However, there may be interchange on a great scale between the minerals within short distances, and glasses may wholly devitrify, but the migrations of material are ordinarily confined within somewhat narrow limits.

The profound changes produced in connection with molecular motions in the dense rocks are largely accomplished by water transporting the compound in solution. The spaces between the particles, even those of subcapillary size, may be penetrated by solutions and the unstable minerals transformed throughout. But under mass static conditions, where the spaces bearing water are very minute, the changes are exceedingly slow. Even in the pre-Cambrian rocks, in the larger dense masses, such readily alterable minerals as nephelene and olivine are found. Olivine occurs extensively in the pre-Cambrian (Keweenawan) diabases and gabbros of the Lake Superior region. Throughout extensive masses in this region the less alterable minerals, augite and basic feldspar, are apparently almost perfectly fresh. The small masses of dense rocks, and especially those which are in the midst of porous rocks, are much more altered.

In the much fractured rocks and in the porous rocks such as sandstones and extrusive igneous rocks and especially the vesicular lavas and porous tuffs, where there is comparatively rapid circulation of water, the migration of materials may be important, the addition of material may be large, and the alterations extend throughout the rock masses. In the case of the amygdaloids the added material has oftentimes been sufficient to completely fill the spaces. Moreover, throughout extensive areas important formations are so altered that no original minerals remain.

In rocks altered under conditions of molecular dynamic action all stages of alteration may be seen, from the comparatively fresh rocks, in which the changes are incipient with the minerals most readily altered, to those rocks in which all alterable minerals have been transformed by metasomatism into others which are permanent under the prevailing conditions.

In the majority of changes by molecular dynamic action, under both (1) and (2), which come within our observation, the chemical reactions usually result in a liberation of heat or running down of energy, under the first part of van't Hoff's law (see page 277). This may be illustrated by hydration, which is, perhaps, the most characteristic change of molecular action, such minerals as chlorite, kaolinite, zeolites, and epidote forming abundantly. The reverse chemical action, that taking place with the absorption of heat, occurs only at great depth under mass static conditions.

Under mass static conditions, at moderate depths, the effect of pressure appears subordinate to that of the chemical reactions. There may be increase of volume as in the case of hydration already mentioned, or there may be contraction as in the case of devitrification of glass, or in the case of recrystallization of minerals which are in a state of strain, and therefore have energy potentialized which is liberated in the process of recrystallization.

DEVITRIFICATION OF GLASS UNDER MASS STATIC CONDITIONS

Barus,* in experiments upon the compressibility of water in capillary tubes at a temperature of 185° C., found that the volume of water apparently decreased as much as 13 per cent in 42 minutes and nearly 18 per cent in an hour. As at lower temperatures he found the compressibility of water to increase at an exceptionally slow rate, he concluded that there must be some other cause than real condensation for the apparent rapid compressibility of water when a temperature of 180° C. to 185° C. was reached. An examination of the tubes in which the experiments were performed showed him that the apparent compressibility was not that of water, but was in fact due to the solution of the silicates of the glass by the water, the material being deposited in crystallized minerals. The change of state resulted in a more compact from. The natural glasses in passing into the crystalline condition decrease in volume in some cases as much as 10 per cent. This decrease in volume in the change of the material of the glass from an amorphous to a crystalline condition gives more room for water, and thus its apparent great compressibility. Barus points out that this decrease in volume of the solids probably involves the evolution of heat. This reaction is clearly a solution and recrystallization under the first part of the law of chemical action and heat (see page 277), and under the law of release of energy by condensation. It is to be noted that the water in this process of recrystallization of glass is not necessarily consumed. It is consumed only in case the crystalline substances forming are hydrated or contain basic water. But even if water is thus consumed, it is evident that a small amount of water may be a medium through which a large amount of work is done. It is clear from the foregoing that in ordinary glass a certain amount of energy is potentialized which may be liberated through the action of water at high temperatures. In this we evidently have an adequate cause for the complete and exceedingly rapid devitrification of old glasses (see pages 290, 291) which have been buried deep below the surface of the earth, and which therefore, by the rise of the temperature

*The compressibility of liquids, by C. Barus: Bull. U. S. Geol. Survey, no. 92, 1892, pp. 78–84.

with depth, have been subjected to the action of water at a temperature of 180° C. or more. This temperature would be reached, with an increment of one degree for 30 meters, at a depth of 5,400 meters.

At less depths the temperature might be 180° C. or more as a consequence of igneous intrusions or other causes, in which case devitrification might be rapid near the surface. Indeed, in areas of regional vulcanism, and often in those of local vulcanism, the lava flows follow one another in such rapid succession that the beds are not cooled before they are buried under other lavas. However, the cooling may be sufficiently rapid so that the lavas solidify at least partly in the form of a glass. In such cases the residual heat of the lava may be sufficient, so that for a long time the glass will be at a temperature above 180° C., and therefore furnish conditions for rapid devitrification.

But one must not conclude that devitrification does not occur at temperatures less than 180° C., and consequently at depths less than 5,400 meters. Indeed, we know that unannealed glass, which cooled irregularly and therefore is in a state of strain—for instance, glass tubing such as is used in the laboratory—partly devitrifies in a few years. Moreover, even if the glass be not in a state of strain, there is every reason to believe that water at temperatures much lower than 180° C. acts upon it slowly, and therefore results in devitrification. Furthermore, it is probable that the process goes on at a sufficient rate, so that during the millions of years of geological time complete devitrification of great masses of natural glass might have taken place comparatively near the surface.

But Barus has shown that 180° C. is a critical temperature, so far as the solubility of glass in water is concerned, and that at temperatures higher than this the rate of action is increased many fold beyond the rate of increase of temperature. Hence we conclude, under ordinary conditions of temperature and mass static conditions, that recrystallization of glass occurs much more rapidly at depths considerably exceeding 5,000 meters than at depths less than 5,000 meters. Since the devitrification of glass results both in liberation of heat and in lessening of volume, it is concluded that this process may occur as deep as observation extends.

Whether the process is slow or fast, it is certain that it has taken place in nature on a great scale. As evidence of this may be cited the well known American instances of the glass of the Original Huronian district described by Williams,* and the glass of South Mountain described by

* Notes on the microscopical characters of rocks from the Sudbury mining district, Canada, by G. H. Williams: Ann. Rept. Geol. and Nat. History Survey of Canada, vol. v, part F, Appendix 1, 1893, pp. 55–82.

Williams and Bascom,* which are completely devitrified. In the papers of these authors many similar instances are cited.

RECRYSTALLIZATION OF MINERALS UNDER MASS STATIC CONDITIONS

To the metasomatic recrystallization of minerals the same principles are applicable as to the devitrification of glass. The chief difference is that the process of solution and re-deposition is presumably slower upon the average for minerals than for glass. The original molecular arrangement is closer, more regular, and harder to break up.

So far as the minerals are for any reason in a state of strain, this is very favorable for solution (see pages 300, 301), and the process under such circumstances goes on at a comparatively rapid rate.

The minerals under mass static conditions, at least within the zone of observation, are usually rearranged or recrystallized according to the first part of van't Hoff's law, with the liberation of heat, as, for instance, by hydration or carbonation. In so far as the minerals are buried to some depth, and consequently under considerable pressure, there is a tendency to change to minerals of a higher specific gravity. The depth at which the pressure is sufficient, without mass dynamic action, to produce dehydration, and to substitute silicon dioxide for carbon dioxide, is uncertain, but that these reactions occur is certain; for no lower limit can be assigned to recrystallization under mass static conditions.

That the recrystallization of great masses of sedimentary and igneous rocks may go far toward or quite to completion under mass static conditions is so well known that the fact need not here be emphasized. One of the best illustrative American localities is that of the Keweenawan series of the Lake Superior region. As shown by Pumpelly † and Irving,‡ the more porous lavas of this series have in many cases largely recrystallized. The less porous ones show extensive alterations. In various regions even great dense igneous masses have been profoundly affected or completely recrystallized throughout by metasomatic change.

However, as subsequently seen, the rocks which have recrystallized under conditions of molecular dynamic action or mass static conditions are easily discriminated from those which have been recrystallized under mass dynamic conditions.

*The volcanic rocks of South Mountain in Pennsylvania and Maryland, by G. H. Williams: Am. Journ. Sci., vol. xliv, 1892, pp. 482–496.

The ancient volcanic rocks of South Mountain, Pennsylvania, by Florence Bascom: Bull. U. S. Geol. Survey, No. 136, 1896, p. 124.

†Metasomatic development of the copper-bearing rocks of Lake Superior, by Raphael Pumpelly: Proc. Am. Acad. Arts and Sciences, vol. xiii, 1878, pp. 253–309.

‡The copper-bearing rocks of Lake Superior, by R. D. Irving: Mon. U. S. Geol. Survey, no. v, 1883, pp. 87–91.

It follows from the foregoing that in metasomatic changes which occur in rocks there is no necessity for the rapid circulation of underground waters, or even for any circulation beyond that necessary to provide water for the hydrated minerals formed by the alterations and to keep intact the minute amount of water in the subcapillary spaces where the attraction extends from wall to wall. If these conditions obtain at a moderate temperature, a very small amount of water may be the medium through which the rocks may be completely altered and recrystallized.

DISTINCTIVE FEATURES OF MOLECULAR DYNAMIC ACTION ARE GROWTH OF LARGE INDIVIDUALS AND PRESERVATION OF TEXTURES

The most distinctive features of molecular dynamic action are the growth of large mineral individuals and the preservation or emphasis of original textures and structures.

The formation of large individuals is a result of the physico-chemical law explained on pages 274, 275, under which large individuals form at the expense of smaller ones. The exceptional growth of certain individuals may be recognized in the very unequal size of the mineral particles, in the enlargement of old individuals, and in the development of porphyritic constituents. The general unevenness of crystal particles in rocks altered under static conditions is so well known that the point need not be emphasized. The enlargement of mineral particles under mass static conditions has been described as occurring in quartz, feldspar, hornblende, augite, garnet, tourmaline, and other minerals, by Sorby, Irving, Becke, Williams, Hobbs, Whittle, myself, and others. As instances of the development of porphyritic constituents may be mentioned garnet, staurolite, andalusite, chloritoid, chlorite, and mica. Such porphyritic constituents may occur in rocks which have undergone no mass dynamic action, or may be present in rocks which have been altered by mass dynamic action. In the latter case they are believed, as explained by Hobbs* and myself,† to have developed, at least in many instances, after mass dynamic action ceased.

The meaning of the numerous interpenetrations of minerals in the recrystallized rocks is rendered clear by the foregoing pages. As a result of the disturbance of equilibrium from any cause, a change may take place. One mineral may grow. At the same time the adjacent mineral may be dissolved. The growth of one in many cases is apparently conditioned by the solution of the other. Cases of this are the growth of

* Phases in the metamorphism of the schists of southern Berkshire, by W. H. Hobbs: Bull. Geol. Soc. Am., vol. iv, 1893, p. 177.

† Principles of North American pre-Cambrian geology, by C. R. Van Hise: Sixteenth Ann. Rept. U. S. Geol. Survey, part I, 1896, pp. 691–694.

magnetite in quartz, the secondary penetration of needles of actinolite and serpentine into this same mineral, and the absorption of biotite and chlorite during the growth of garnet and staurolite.

However profound the alterations of molecular dynamic action, the original textures and structures of the rock may not be greatly affected. It may be that all of the original minerals composing the rock are completely changed, and yet the original igneous or other textures be perfectly preserved. The case is parallel to that of petrefaction of a wood in which no particle of the woody fiber remains, and yet the textures of the living tissue are almost perfectly preserved. The modifications of molecular dynamic action are mainly changes of substance, not changes of form. Thus all the textures characteristic of igneous rocks, such as granolitic, ophitic, porphyritic, etcetera, may be almost completely preserved in a rock which has altered throughout. This is illustrated in the diabase dikes in the iron-bearing formation of the Penokee series of Michigan and Wisconsin. These dikes in the black impervious slates are diabases, but their continuations in the iron-bearing formation do not contain one vestige of any original mineral, but are ferruginous, hydrated, aluminium silicates, which in composition correspond very closely to kaolinite.* Yet the texture in the altered rock and in the diabase is the same.

Indeed, not only may there be no tendency to destroy textures and structures which were originally present, but there may be a tendency to emphasize them. This emphasizing of old textures and structures results from the fact that solutions work along openings and surfaces of weakness. At any place in which water is present in greater volume than the average amount, or is more than usually active, there may be greater than average solution and deposition, and thus emphasis of the old texture or structure. Common cases are the emphasis of perlitic cracks and bedding planes.

However, where large individuals alter to many small particles or undergo a secondary enlargement with needle-like terminations, or are altered in various other ways, the original textures may become much less definite than they were originally, although the process of modification rarely goes so far as to obliterate original textures.

As a result of the preservation or emphasis of original textures during molecular dynamic metamorphism, it may happen that somewhat extensive changes in a rock may be overlooked or ignored. Those who are most familiar with the recent, little modified rocks are inclined to explain the phenomena they see in the rocks being studied as original.

*The Penokee Iron-bearing series of Michigan and Wisconsin, by R. D. Irving and C. R. Van Hise: Mon. U. S. Geol. Survey, no. xix, 1892, pp. 357, 358.

Those who have been working among the ancient and therefore more modified rocks are inclined to explain similar phenomena as the result of alteration. In each individual case the phenomena must be studied in the field and in the laboratory, taking into account all the evidence, in order to ascertain the actual truth; for it is certain that such phenomena as amphibole surrounding pyroxene cores and pegmatitic textures may be due to primary crystallization or to secondary alteration, and the appearance in the two cases be much the same, if not identical.

Mass dynamic Action and accompanying molecular dynamic Action

It has already been stated that in connection with mass dynamic action, molecular dynamic action invariably occurs. The kind and amount of resultant metamorphism varies greatly, depending upon depth, upon the particular kind of deformation, and upon other factors. It has been shown in another place that, depending upon depth, there are three important zones of deformation of which we have definite knowledge: (1) An upper zone of fracture, (2) an intermediate zone of fracture and flowage, and (3) a lower zone of flowage.*

ZONE OF FRACTURE

In the zone of fracture deformation is accomplished by considerable movements along surfaces or zones, with little or no movements between these planes or zones. Such fractures are faults, joints, fissility, bedding partings, and the spaces of autoclastic rocks. The rocks are broken by these fractures into great regular masses, blocks, or leaves or into the irregular fragments of a dynamic breccia. Into these openings water readily enters to assist in the modifications. The movements between the individual mineral particles are largely confined to thin layers along the walls of the openings, and the conditions may be here those of important interior deformation, but for the masses of rock between the fractures the conditions are those of molecular dynamic action already described, and the changes are correspondingly slow. The rapid changes are confined to the material adjacent to the openings. From the places of entrance waters may permeate the adjacent rocks to a greater or less distance, and consequently molecular dynamic metamorphism may occur to a much greater extent than it would were it not for the fracturing. The alterations of the thin layers of material adjacent to the openings are by interior movements, which are in all respects like those of kneading described under zone of flowage.

* Principles of North American pre-Cambrian geology, by C. R. Van Hise: Sixteenth Ann. Rept. U. S. Geol. Survey, part I, 1896, pp. 589–595.

It follows from the foregoing that the deformation accomplished by widely spaced fractures does not result in the obliteration of the original textures and structures, except adjacent to the fractures. The rocks are merely jointed, sliced, piled up, or brecciated, and in each block or slice the alterations are metasomatic, or those of molecular dynamic action.

ZONE OF COMBINED FRACTURE AND FLOWAGE

Since the metamorphism of the intermediate zone of fracture and flowage combines the phenomena of the zone of fracture and the zone of flowage, its consideration is deferred until after the zone of flowage is treated.

ZONE OF FLOWAGE

At the outset it may be said that the process of rock flowage is very different from the flowage of a liquid.

It has been explained in another place * that in the deep-seated zone of rock flowage the process of deformation is similar to that of mashing or kneading. There every particle, small or great, takes part in the deformation.

As soon as interior movements begin the destruction of the original textures and structures begins and goes on very rapidly, so that with comparatively little motion the original textures may be wholly destroyed. For instance, such rocks as quartzose sandstones, which retain their structures for indefinite periods if there be no mass action, even when buried under thousands of feet of other rocks, when deformed by mashing rapidly lose all clastic textures. In the same way the textures which are characteristic of igneous rocks rapidly disappear by mashing. In the place of the original textures, whether those of sedimentary or igneous rocks, there appear peculiar textures and structures referred to subsequently as characteristic of mass dynamic metamorphism.

During the interior mass movements of rocks water makes its way between the particles much more readily than under conditions of quiescence. This follows partly from the movements and partly from the heat developed by the movements. The increased temperature results in decreasing the viscosity of the water, and it has been seen (pages 272, 273) that low viscosity is of great importance in the penetration of water through minute spaces.

Consequent upon interior mass movement two kinds of deformation occur, granulation and recrystallization. Between the two are all gradations.

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* Principles, cit., pp. 694–696.

Granulation.—Where the movements result in granulation this exposes large surfaces to the action of the contained water. The dissolving power of water when not nearly saturated is almost directly in proportion to the area upon which it can act. If the grains of a rock be broken by granulation into particles having radii .1 of those of the original grains, each small grain will have .001 the volume of an original grain, and the total surfaces of the fewer original grains will be to the total surfaces of the more numerous grains as 1 : 10. If the granulation goes so far as to give the granules radii averaging only .01 of that of the original grains, each small grain will have .000001 of the volume of the original grains, and the total surfaces for the original grains will be to the total surfaces of the granules as 1 : 100. This last is not an extreme case, for in the Original Laurentian district of Canada, described by Adams,* the ratios between the diameter of the granules and original particles must be at least 1 : 100.

In different cases the average degree of granulation varies greatly. The amount of granulation depends upon the size of the particles and upon the mineral character of the particles. At a stage when the smaller mineral particles are granulated throughout, the larger mineral particles may have only a narrow outer zone affected. In a more advanced stage the larger particles may be broken throughout, and in cases of extreme deformation the largest pebbles or boulders in sedimentary formations may be mashed into thin layers not recognizable as clastic fragments, each being composed of a multitude of individual particles. Also it is well known that some minerals may be much more readily granulated than others. As a common case, may be mentioned quartz and feldspar. In many rocks in which the former mineral is largely granulated the latter mineral is little affected.

Recrystallization.—Facts of recrystallization.—One might perhaps expect from the foregoing that the more profound the kneading the finer would be the granulation of the altered rock, but this is not the case. Many of the most profoundly altered rocks, instead of being extremely fine grained, are somewhat coarsely crystalline.

This anomaly was long a puzzle to me. In examining the mashed rocks I found that under certain conditions the more profound the mashing the finer the granulation; but in tracing the process to the extreme of granulation I found there was always a limit beyond which the particles did not become more finely granulated. On the contrary, at a certain stage a reverse tendency appeared, and the particles instead of

* Report on the geology of a portion of the Laurentian area lying to the north of the island of Montreal, by F. D. Adams: Ann. Rept. Geol. Survey of Canada, vol. viii, part J, 1896, p. 108, pl. vii, fig. C.

becoming smaller gradually became larger. This increase in coarseness of the mineral particles may be followed through all stages to the coarsely crystalline schists.

In the granulated rocks the mineral particles everywhere show strongly the strains of undulatory extinction, but the mineral particles of many of the coarsely crystalline schists show no more than slight strain shadows. The coarsely crystalline, perfectly schistose rocks, nearly free from strain shadows, are always found to be those which have been deeply buried and profoundly deformed or adjacent to great intrusive masses, or both. It is therefore clear that those rocks represent the most advanced stages of metamorphism.

It is generally agreed that the crystalline schists of this character have been recrystallized throughout, and therefore strongly contrast with those rocks which have been granulated. However, the granulated and recrystallized rocks are not separated sharply from each other (see pages 305–312), but, on the contrary, there is every gradation between the two. If in the altered sedimentary rocks one passes from a place of granulation to one of recrystallization, he finds that recrystallization of the matrix begins while granulation of the larger particles is still going on.

The original rock may have varied greatly in the coarseness of its constituent particles. In an intermediate stage the matrix may have completely recrystallized and the granulation of the coarser particles be still incomplete. As a consequence, the mineral particles of the matrix are increasing in size at the same time the larger particles are being decreased in size.

At a certain stage the larger grains are granulated into particles which average about the same magnitude as those which have crystallized out of a fine-grained and perhaps irresolvable matrix, and moreover the grains which have formed from the matrix approximate uniformity of size. Thus there is a marked tendency toward uniformity in the size of the grains of the metamorphosed rocks, and this tendency is ordinarily dominant in the crystalline schists so long as mass deformation continues. This statement is more nearly accurate in reference to the particles of each mineral than to particles of different minerals. This tendency toward uniformity controls, notwithstanding the principle that under ordinary conditions large mineral particles grow at the expense of smaller ones (see pages 274, 275); for under mass dynamic conditions a large grain, whether original or produced by uneven growth, is especially exposed to the mechanical stresses, and therefore is granulated in part or put in a state of strain, and thus may be more readily attacked by the solutions. Some of the properly oriented smaller particles may themselves grow at the expense of the larger ones or the small ones not properly oriented or happily placed, and thus in the first case reverse the tendency of mass static conditions. Thus is explained the characteristic uniformity in the size of the particles of the crystalline schists which have not been modified since mass dynamic action ceased. However, in some cases, where the mineral particles are properly oriented, as explained on page 305, the tendency for large individuals to grow at the expense of smaller ones may control and porphyritic textured crystalline schists be produced.

The second characteristic feature of the recrystallized schistose rocks is that the mineral particles show a marked tendency toward regular orientation. This orientation may consist in the particles having their major, mean, and minor diameters in approximately a common direction; or in certain species having their crystallographic axes in a nearly common direction, as result of which the like cleavage of all the particles of a certain mineral is approximately in the same plane; or in having the two combined. This arrangement, where marked, transforms the rocks into cleavable slates or schists.

The most important of the minerals the particles of which show a similar crystallographic orientation are micas, and especially biotite and muscovite. With these minerals similarity of orientation is usual. The minerals next in importance which frequently show a marked tendency toward similar crystallographic orientation are feldspar, chlorite, and amphibole. Other less important minerals are known to show the same phenomena. Of course, it is understood that the crystallographic orientation is in no case perfect, but with mica it may approach perfection. From the extreme of regularity of orientation shown by mica in the typical crystalline schists to the random orientation of some of the minerals in the same schist there are gradations; also there are gradations from the crystalline schists to rocks recrystallized under mass static conditions where none of the minerals show a marked tendency to similar crystallographic orientation.

In many cases the similar orientation of mineral particles in a typical crystalline schist may have been greatly disturbed by subsequent deformation near the surface, and therefore in the zone of fracture. Under such conditions shearing fractures may be produced parallel to the schistosity, and the shearing motion between the layers may largely destroy the original regularity of the oriented particles.

Some of the mineral constituents of igneous rocks which have not been recrystallized show a tendency toward a parallel crystallographic orientation. However, with this structure are other structures characteristic of rocks crystallizing from a magma. I know of no instance in which an unaltered igneous rock so closely resembles the crystalline schists that there is any trouble in discriminating between them.

It has been noted that in the production of the characteristic texture and structure of the crystalline schists, that the original textures and even structures may be destroyed, whether they be those of sedimentary or igneous rocks. In passing from an area of molecular dynamic action to an area of mass dynamic action all stages of obliteration of the original textures and structures and the development of the new textures and structures may often be traced. In an intermediate stage the larger particles or more refractory minerals may show the textures of the original rock, the matrix of the same rock, however, having the texture of a recrystallized rock. In instances of extreme alteration no trace of the original texture remains even in those cases where the rocks were coarse conglomerates or coarse porphyritic igneous rocks, and the secondary structure may traverse the original structures or the latter may be wholly obliterated.

Thus mass dynamic action stands in sharp contrast to molecular dynamic action, in so far as textures and structures are concerned. By mass dynamic action there is a tendency to destroy old textures and to produce a characteristic texture the more important features of which are mineral particles of uniform size and parallel orientation, and there is a tendency to destroy old structures and to produce a characteristic slaty or schistose structure. Under conditions of molecular dynamic action the original textures and structures are preserved, although they may be somewhat modified or emphasized by the unequal size and lack of orientation of the mineral particles.

Theory of recrystallizaton.—In the process of recrystallization all the forces described (pages 275–277) are at work.

In the deep-seated zone where the process occurs the temperature is considerably higher than at the surface, because of the increase of temperature due to depth, because of heat resulting from mechanical action, and in many districts because of heat derived from intrusive igneous rocks. Water occupies all the openings to those of subcapillary size. Moreover, this water has about the temperature of the adjacent rocks, and is therefore extremely active. Taking the ordinary gradient, the temperature at a depth of 3,000 meters would be 100° C., at 6,000 meters 200° C., and at 9,000 meters 300° C. At these temperatures the material would ordinarily be water and not steam, for the pressure of the superincumbent column of water is more than sufficient to prevent it from passing into the condition of a gas. However, as a result of the heat of mechanical action or of igneous intrusion, or both, the temperature at a given depth may become so high that the water may at least locally and for short times be in the form of water vapor.

As a result of the mechanical forces the mineral particles are either strained within the elastic limit or granulated, and with the last the former occurs, for even where the original mineral particles are broken the individual granules ordinarily show strain-shadows.

The question of the relation of a state of strain in minerals to the potentialized energy here naturally arises. Barus* has shown in the case of strained metals that the work done in straining them is very largely potentialized. In "glass-hard" steel, strained to the point of rupture, 50 per cent of the energy used was potentialized; in brass, 40 per cent; in copper, 25 per cent. A larger percentage of the energy was potentialized in the earlier stages of strain than in the later stages. The explosive action of a Prince Rupert drop, when a point is broken, shows that a large amount of energy is potentialized, or that the glass is in a high state of strain.

The experiments of Barus and the condition of the Rupert drops show that in strained minerals energy is probably potentialized. The fact that glass releases itself from strain by crystallization, as noted (page 289), may be taken as evidence that minerals in a similar condition are more readily rearranged by the chemical forces through solution than they would be in an unstrained condition. In an interior state of strain we therefore have a cause for recrystallization. This cause, high temperature, and unequal distribution of exterior pressures—which always must be a condition in rocks because of the unequal strength of the minerals—appear to be sufficient reasons for recrystallization in rocks which have been profoundly affected by mass dynamic action. Slight movement disturbs the equilibrium. As soon as a state of strain is produced the processes of solution and recrystallization set to work to adjust the minerals.

The process in many respects is analogous to the very rapid solution and crystallization of glass described by Barus (see pages 289, 290). It may be recalled that 180° C. is a critical temperature in the crystallization of glass. At temperatures as high or higher than this, which undoubtedly prevail in the deepest-seated zone of deformation, the process can go on with comparative rapidity. At any moment the substances are present almost wholly as minerals. However, superheated water is in the capillary and subcapillary spaces between the particles, and through this as a medium adjustment by solution and recrystallization goes on continuously during the deformation. At any given moment only an exceedingly small part of the material is in solution; but under the kinetic theory of solutions all materials in a state of strain, or subject to unequal pressure, or not in a compact state, will be more ready

*The mechanism of solid viscosity, by C. Barus: Bull. U. S. Geol. Survey, no. 94, 1892, pp. 107, 108.

FIG. 1—THIN SECTION OF MASHED QUARTZ-PORPHYRY. AFTER FUTTERER.

FIG. 2—MUSCOVITE-BIOTITE-SCHIST. POLARIZED LIGHT.

to part with their molecules than the minerals not so conditioned. Thus, from all mineral particles which are under one or all of these conditions, particles will be filed off or solution will be constantly taking place. Simultaneous with this, from the solution there will be deposition of material in more compact molecules than those dissolved at the places where the pressure on the mineral particles is less than the average.

Two of the best minerals to illustrate the process are quartz and mica. The first recrystallizes somewhat readily, and the second develops on an extensive scale in the crystalline schists. That quartz occurs abundantly in flat individuals in the crystalline schists is well known. Moreover, it is known in many cases that the flat individuals are largely the equivalent of individual crystals which have had a nearly spherical form. As illustrations of flat grains of this mineral are the quartzes of the quartz-porphyries described by Futterer* (plate 19, figure 1) and mica-schists from the Black Hills† (plate 19, figure 2), which I have described. The many flat particles have exactly the appearance they would have had if the material could have been pressed out and had recrystallized anew as a single individual and subsequently had been somewhat strained. In some cases the flat individuals have a somewhat curved form (plate 19. figure 1; also see page 323). The explanation suggested by Adams for the deformation of the quartz of the leaf gneisses of the Original Laurentian district is movement along gliding planes, as advocated by Mügge in reference to ice crystals. However, this explanation seems inadequate to explain the phenomenon above described, for two reasons: First, the greater dimensions of the flat quartz individuals always correspond to the schistosity, and are wholly independent of the orientation of the original particles, and therefore independent of their gliding or other definite planes. If gliding had taken place, this must have occurred along definite crystal planes. Second, as shown (page 303), in many cases during recrystallization the material of a multitude of particles is built into a single particle. Hence it seems perfectly clear that gliding along any set of definite planes will not explain the facts. The phenomena are believed to be due to solution and deposition, or recrystallization, as already explained. The particles of the quartz not fortunately oriented at places under great stress—that is, upon the exposed parts of the grains—are taken into solution and transported to the borders of the fortunately oriented individuals, where less stressed, and redeposited; or, the material dissolved from the more exposed part of a grain may be deposited on another part of the same grain. Thus the

* Die "Ganggranite" von Grossachsen, und die Quartzporphyre von Thal im Thuringer Wald, by Karl Futterer: Heidelberg, 1890, pp. 27–47.

† The pre-Cambrian rocks of the Black Hills, by C. R. Van Hise: Bull. Geol. Soc. Am., vol. i, 1890, pp. 222–226, 244.

quartz of a given flat granule may be largely the same quartz as that of the original grain, but it has been dissolved and redeposited, perhaps repeatedly in part.

Mica, and especially biotite and muscovite, are very abundant in the crystalline schists. Moreover, in proportion as the rocks approach typical schists, the particles of these minerals are large, of approximately uniform size, and oriented crystallographically. In the original sedimentary rocks from which the mica-schists most extensively form, the micas are rare constituents, except in the coarse arkoses, and where they occur the particles are large, more or less irregularly arranged, often somewhat decomposed, and are readily discriminated from the regularly arranged, fresh micas of the crystalline schists. These facts are so well known that nearly all petrographers who have studied thin sections of the crystalline schists have regarded such micas as authigenic. Chemical analyses show that soils, muds, clays, and shales contain the elements out of which mica may develop.* Many of these elements occur in hydrated compounds, such as kaolinite, zeolite, chlorite, limonite, etcetera. In the crystalline schists which develop from such sediments these hydrated minerals may be altogether absent, their places being largely taken by micas. It is clear that during the metamorphism of the rocks these hydrated minerals are taken in solution, and from such solutions the mica molecules, containing little water, are deposited. The solution and deposition give the material a less hydrated and more compact form; therefore the original material as compared with the resultant material contains potential energy, which is liberated during the process of crystallization. During the process at numerous places mica leaflets oriented by the differential stresses (see pages 324, 325) begin to form. The minute leaflets once formed serve as nuclei upon which the material which is continuously taken into solution may be deposited. The mineral particles grow somewhat uniformly, being subject to the same laws in this respect as original mineral particles (see pages 297, 298). By studying a series of thin sections from any of the districts in which the rocks of a formation vary from little altered to completely metamorphosed rocks all stages of the process may be seen, from that in which the original hydrated minerals are abundant and mica is absent to that in which the former are absent and mica is abundant.

In the foregoing we apparently have the explanation of the large average size of the mineral particles which constitute the crystalline schists formed at considerable depth by dynamic action. They are continuous growths during deformation by solution and redeposition.

*Analyses of rocks and analytical methods, by F. W. Clarke and W. F. Hillebrand: Bull. U. S. Geol. Survey, no. 148, 1897, pp. 277–301.

As excellent illustrations of the development of rocks showing all or many stages of the recrystallization of quartz and the development of mica may be cited the mica-schists and mica-gneisses which I have described in the Penokee and Marquette districts of Michigan and in the Black Hills of Dakota (plate 19, figure 2).*

As a beautiful illustration of the transition from finely crystalline to coarsely crystalline rocks may be cited the iron-bearing formation of the Marquette district of Michigan.† The deformation of this formation was mainly by recrystallization. In the eastern part of the district granulation and wider spaced fractures occurred to some extent, but the temperature was not high enough for coarse crystallization, or some other condition was lacking. In the western part of the district, while the rocks were probably not more deeply buried, the deformation was much more profound, and because of this it is probable that the temperature reached 180° C. or more. As a consequence the mineral particles grew to a much larger size. At places in the eastern part of the district, where the conditions were least favorable for recrystallization, the quartz granules in the jaspilite average about .01 millimeter in diameter. In the western part of the district, where the conditions were more favorable, the quartz particles in the coarsest jaspilite average about 1 millimeter in diameter. Moreover, they show little strain. These particles therefore average about a million times greater than those of the eastern part of the district, and hence to form one new individual the material of a million old particles was utilized. This illustration therefore gives conclusive evidence of the capacity of quartz to accommodate itself to the most intense deformation by recrystallization.

Recrystallization lags behind deformation.—In the deep-seated zone adjustment may not lag far behind the disturbing forces. However, in most cases there is apparently some lag. In the most regularly laminated of the crystalline schists a close examination usually shows a slight undulatory extinction, and therefore a state of strain in the minerals, showing that recrystallization has not exactly kept pace with deformation, or else that they have been somewhat deformed nearer the surface since recrystallization.

Where such subsequent deformation has not taken place, the amount of strain-shadows or granulation is thought in many cases to be a measure of the amount that molecular readjustment lags behind the disturbing movement. In the typical crystalline schists strain is in many cases scarcely perceptible. In other cases all of the mineral

* Mon. xxviii, cit., pp. 448–450, 452–454, 456–459. Mon. xix, cit., pp. 305–318. The pre-Cambrian rocks of the Black Hills, by C. R. Van Hise: Bull. Geol. Soc. Am., vol. 1, 1890, pp. 222–229.

† Mon. xxviii, cit., pp. 381, 391.

particles show marked strain-shadows. In still other cases the strain-shadows are accompanied by more or less of granulation, and this phase of the rocks grades into the ordinary granulated rocks. Thus there are all gradations between molecular readjustment or recrystallization almost *pari passu* with deformation, and readjustment almost wholly by granulation.

Evidence that recrystallization does nearly keep pace with deformation in the case of the crystalline schists consists partly in the absence of marked strain structures, for it is to be supposed that if recrystallization did not nearly keep pace with deformation the result would be that the mineral particles would show important strain-shadows or even granulation. The texture characteristic of the crystalline schists (described, pages 297–299) is itself further evidence for continuous recrystallization by solution during deformation. It is a texture peculiar to the crystalline schists. If the minerals were not readjusted in a continuous fashion they must have become granulated by the mechanical forces. If they had become fused into a magma, from that state the material would recrystallize with textures peculiar to the igneous rocks. The regular arrangement of the mineral particles with their longer axes or definite planes at right angles to the direction of greatest pressure is just what would be expected if the contained water is everywhere taking material into solution at the points of great strain, and adding this material at the edges of the particles, and thus continuously building them out laterally.

Further evidence that recrystallization nearly keeps pace with deformation is found in the porphyritic minerals which frequently occur in the crystalline schists. Some of the more common of these porphyritic minerals mentioned (page 292) are garnet, staurolite, andalusite, feldspar, hornblende, chloritoid, chlorite, and mica. Such porphyritic minerals ordinarily show no perceptible strain. They frequently lie with their longer axes or readiest cleavage across the schistosity. This is true even of mica and chloritoid, the cleavage of the porphyritic constituents cutting directly across the cleavage of the abundant small individuals of mica which accord with the schistosity. It has been maintained (page 292) that such porphyritic minerals have developed under static conditions after mass movement has ceased. These porphyritic minerals seem to be evidence that the differential stresses of static conditions are ordinarily not sufficient to control the orientation of the mineral particles; that in order to do this the differential stress must be sufficient to produce actual movement throughout the mass of the rocks. If this be so, we must suppose that the orientation of the minerals producing schistosity occurred during the movement itself, or, in other words, that recrystallization nearly kept pace with the movements.

During movement, in some cases, the tendency for large individuals to grow at the expense of smaller ones may control, and properly oriented individuals grow to a porphyritic size. This is beautifully illustrated by some of the albite gneiss of Hoosac mountain and by parts of the augen gneiss of the French Broad river. The porphyritic feldspars show a marked tendency toward crystallographic orientation, the cleavages of the feldspars corresponding with the cleavages of the rocks.

This argument applies equally to the cases of the parallel crystallographic orientation of individuals which occasionally occur in rocks crystallizing directly from magmas. Feldspar is not infrequently oriented in such rocks, and the phenomenon is known in reference to other minerals.

Conclusion.—From the foregoing it is concluded that the development of the crystalline schists is to be explained as a process of chemical reaction induced by mechanical action, resulting in the constant solution and deposition of the material so as to accommodate it to the changing form of the mass.

Relations of granulation and recrystallization.—Whether granulation or recrystallization is the dominant process in a given place in the zone of flowage depends upon many factors. Some of these factors are the character of the material, water content, temperature, pressure, and rapidity of deformation.

Character of material.—Whether granulation or recrystallization occurs depends to a considerable extent upon the character of the material. The difference appears as a consequence of the presence of different materials in varying proportions in different rocks.

In a rock the same mineral may be partly granulated and partly recrystallized. Even the individual grains of a mineral may exhibit the two processes in various proportions In the latter case the fracturing may be along the borders of the individuals, may extend entirely across them, or granulate them throughout. The simultaneous solutions and depositions may be along the borders of the original or the secondary granules; they may be in the spaces produced by the fracturing; they may regenerate the old mineral particles throughout. Any of the deposited material may be as independent individuals or as enlargements of original grains or mechanical granules. In some cases the separated granules and cement have a common or nearly common orientation. In the different particles of the same mineral in a given rock granulation or recrystallization may be the dominant process.

In the same rock mass certain minerals may be recrystallized and others granulated or retain their integrity. For instance, it is well known that quartz suffers granulation and recrystallization much more readily than feldspar. Recrystallization is illustrated by the flat individuals of quartz in the quartz-porphyries described by Futterer* (plate 19, figure 1) and in many other rocks in which the feldspars have either been granulated or little affected.

At this time I shall make no attempt to compare the various minerals with one another with reference to ease of recrystallization. There are all gradations, from calcite, which can be easily recrystallized in the laboratory by the passage of water through finely powdered material under very moderate pressure, to the more refractory minerals, such as feldspar.

Since some minerals when strained recrystallize much more readily than other minerals, it follows that a formation composed chiefly of one class of minerals may be largely recrystallized, while an adjacent set of rocks composed of another set of minerals may be only partially recrystallized. One formation might thus show complete granulation or other important strains, while the recrystallization of the adjacent formation, because of the greater mobility of its mineral particles, might nearly keep pace with the deformation. One rock might show the textures and structures of the crystalline schists with more or less residual strain effects, while an interlaminated rock might so readily recrystallize as to take on a granolitic texture after movement had ceased. As an illustration of this are the closely associated gneisses and marbles of the Adirondacks and of the Hastings series of Canada. Many of the gneisses show marked strains in various localities, while interstratified with these are coarsely crystalline marbles, showing no other strains than those of polysynthetic twinning and similar phenomena, which may have been developed by the slight stresses to which the material was subjected in section cutting in the laboratory.

No better example is known to me of the influence of the character of the material upon the gradations and relations between granulation and recrystallization than the Algonkian rocks of the Black Hills,† described in volume I of this Bulletin. There conglomerates, quartzites, mica-slates, mica-schists, and mica-gneisses occur in intimate relations to one another. Nearly every phase of deformation, from that of granulation as a dominant process to that of recrystallization, is represented.

Water content.—Absence of water is favorable to granulation; presence of water is favorable to recrystallization. If a series be so dense or is of such an origin as to contain comparatively little water, even if other conditions be favorable, deformation by granulation rather than by recrystallization may occur. Another series in every other respect under

*Adams, op. cit., pp. 47, 48.

†The pre-Cambrian of the Black Hills, by C. R. Van Hise: Bull. Geol. Soc. Am., vol. i, 1891, pp. 214–229.

similar conditions, but which contains water, might be adjusted by recrystallization and form coarsely crystalline schists. This principle is believed to explain the difference of the character of the deformation of the different formations for many districts. It is a well known fact that different rock masses of similar chemical composition in the same district vary greatly in the character of the deformation, some formations yielding by granulation, others by recrystallization. In general the sedimentary rocks contain a considerable percentage of water, and therefore when deformed are recrystallized. The same is true of the porous igneous rocks, such as lavas and tuffs. In contrast with these are the massive igneous rocks, and especially the plutonic rocks which contain little water, and when deformed are apt to be granulated rather than recrystallized. One of the best districts to illustrate this principle is the Original Laurentian area described by Adams.* In this district are the anorthosites, the Grenville sedimentary series, and the Basement Gneiss of igneous origin. Adams' careful descriptions show that the most fundamental point of difference between the three classes of rocks in their response to deformation is in reference to recrystallization and granulation. The sedimentary rocks of the Grenville series have been completely recrystallized and are typical crystalline schists.† The igneous gneisses are largely deformed by granulation, but "the granulation has perhaps been effected in part at least by recrystallization."‡ The anorthosites have been almost wholly deformed by granulation.§ Corresponding exactly with these facts are the contents of water. Analyses of three recrystallized Grenville gneisses give an average content of water of 1.46 per cent.‖ An analysis of one partly granulated and partly recrystallized gneiss of igneous origin gives .70 per cent of water.¶ An analysis of granulated anorthosites gives only .55 per cent of water.**

As examples of recrystallized schists of igneous origin may be mentioned the Kitchi schists, the mica-schists, and the Palmer gneisses of the Basement Complex of the Marquette district of Michigan. Two analyses of the Kitchi schists showed respectively 2.51 per cent and 2.70 per cent of water above 100° C.†† A mica-schist gave off 2.04 per cent of water above 100° C.‡‡ A Palmer gneiss gave off 2.33 per cent of water above 100° C.§§ Partial analyses of two other mica-schists from the same local-

* Op. cit., p. 184.
† Loc. cit., pp. 51, 61.
‡ Loc. cit., p. 45.
§ Loc. cit., pp. 102, 105.
‖ Loc. cit., p. 58.
¶ Loc. cit., p. 43.
** Loc. cit., p. 130.
†† Mon. xxviii, cit., p. 168.
‡‡ Ibid., p. 202, analysis no. 6.
§§ Ibid., p. 217.

ity as the mica-schist referred to, which show a cataclastic or granulated structure, unfortunately do not include water determinations.

The foregoing analyses of recrystallized schists from the Archean and Algonkian may be taken as typical of the recrystallized schists of all ages the world over. This is shown to be evident by running through the various analyses of the recrystallized schists in any of the published tables of analyses. Such tables show that the recrystallized schists average more, rather than less, than 1.50 per cent of water, and in many cases that they contain more than 2 per cent of water.

In Clarke and Hillebrand's book of analyses,* besides those mentioned, are found three other analyses of typical crystalline schists. The analyses are of typical gneiss, derived from basic granite, city of Washington, with a water content, above 110° C., of 1.97 per cent, and two plagioclase-gneisses from the Sierra Nevada, with a water content, above 110° C., of 1.71 and 1.47 per cent respectively. These analyses, with those already quoted, cover all of the schists cited in the Bulletin which, from the available descriptions, can be ascertained to be certainly recrystallized. They are here included to show that in this bulletin there is no exception to the rule laid down.

It is noted in the analyses quoted that the water contents are amounts given off above 100° C.; in other words, the water is combined water. This point is of importance as showing at the time metamorphism occurred that water was present in sufficient amount, so that upon an average 1.5 per cent or more was worked into or was already within the body of the minerals. These amounts of the combined water are, of course, no measure of the amount of the water, free and combined, contained by the rock during the metamorphosing process. Indeed, it is highly probable that the amount of combined water in the later stages of the process, in the case at least of the sedimentary rocks, is lower than in the earlier stages of the process, and consequently water is continuously driven off during the process, thus ever renewing the water films in the subcapillary spaces and furnishing a medium for solution and redeposition. This may be illustrated by the analyses of slates and shales, and clays and soils, given by Clarke and Hillebrand. Twenty slates and shales from Vermont, Colorado, and California gave an average of 4.42 per cent of water above 100° C. Fourteen slates and shales from Vermont, New York, Kentucky, Georgia, and Alabama gave an average of 4.34 percentage of water above 110° C.† It is well known that slates and shales when profoundly metamorphosed by mass dynamic action produce mica-schists or mica-gneisses.

* Analyses of rocks and analytical methods, U. S. Geological Survey, by F. W. Clarke and W. F. Hillebrand: Bull. U. S. Geol. Survey, no. 148, 1897.

† Loc. cit., pp. 277–286.

Therefore these slates and shales contain in combination not only a sufficient amount of water to satisfy the requirements as to combined water in the completely metamorphosed schists, but they contain an excess of water which is probably steadily given off during the process of metamorphism, and thus they constantly furnish a sufficient supply of the medium through which recrystallization can take place.

The slates and shales themselves are rocks partly metamorphosed by mass dynamic action, and they doubtless lost combined water in the process of metamorphism, just as additional water would be lost in their further metamorphism to schists or gneisses. The original mudstones from which the shales and slates were produced may be presumed to have contained at least as much water as soils and clays. Sixteen analyses of soils and clays from Pennsylvania, Florida, and Colorado gave an average loss of water at or above 100° C. of 7.15 per cent. Six analyses of clays and soils from Virginia gave an average loss of water above 110° C. of 8.61 per cent. Forty-four analyses of clays and soils from Massachusatts, South Carolina, Alabama, Missouri, Colorado, Nevada, and California gave an average loss of water upon ignition of 8.10 per cent.*

If the analyses quoted on the previous pages were taken as typical of the finer grained sedimentary rocks, it would be concluded that in the metamorphism of mudstones to shales and slates about one-half of the combined water is lost, and that in the further metamorphism of the shales and slates to the mica-schists and mica-gneisses one-half of this residual water content is lost.

These facts give further support to the argument for the necessity of water at the beginning of the dynamic process in order that recrystallization shall readily occur. If the massive original rocks at the beginning of the mass movement did not contain sufficient amounts of water so that recrystallization could take place, it does not appear that they are likely to gain sufficient water from an outside source, and hence the frequent granulation of the plutonic rocks when deformed. However in proportion as the rocks are deep seated, a less amount of water probably suffices for the process of recrystallization.

Though aside from the present discussion, the steadily lessening amount of combined water with increasing metamorphism is illustrative of the fact, already explained (see pages 280, 281), that the deep-seated zone of recrystallization, as a result of dynamic metamorphism, is one of dehydration.

In opposition to this, the alterations under mass static conditions, and especially under conditions of small depth, are those of hydration. Many

* Loc. cit., pp. 287-301.

of the rocks metamorphosed by metasomatic change, without mass dynamic action, contain as high or higher percentages of water than the soils and clays the water contents of which have been quoted. If later such hydrated rocks, whether of igneous or aqueous origin, were subjected to mass dynamic action, under proper conditions, recrystallized schists might be developed.

The foregoing facts seem to show that whether granulation or recrystallization occurs in a given district in rocks of a certain chemical composition does not depend upon whether the rocks are igneous or aqueous, but, other things being equal, upon whether sufficient water is present, by means of which recrystallization may occur. As this is more frequently the state of affairs in the sedimentary rocks than in the igneous rocks, it follows that the sedimentary rocks are more frequently recrystallized than the igneous rocks, though in many instances recrystallization rather than granulation has been the process of modification for the igneous rocks.

The experimental work of Adams and Nicholson * upon the deformation of marble is fully confirmatory of the above conclusions in reference to the influence which water so frequently has in determining whether granulation or recrystallization occurs. Thus far their experiments have been performed without the presence of water, and granulation has been the natural result. Particles were subjected to sufficient pressure to bring them close enough to one another to be within the sphere of molecular attraction, and adhesion or welding was the result—a result easily obtained with the soft metals, but requiring great pressure in the case of brittle substances, such as calcite. Adams now proposes to make similar experiments with the presence of water. When these are performed, if under proper conditions, it may be anticipated that recrystallization, instead of granulation, to some extent at least, will take place.

Temperature.—Low temperature is favorable to granulation; high temperature is favorable to recrystallization. The temperature of 180° C. is more nearly crucial between the processes than any other. Below 180° C. granulation is likely to be prevalent, especially if the deformation is rapid. Above 180° C. recrystallization is so rapid that the mechanical strains probably do not go far before they are largely obliterated by recrystallization.

Temperature increases with depth; therefore the less the depth, the greater the tendency to deformation by granulation; the greater the depth, the greater the tendency for recrystallization. Since 180° C. is a

* Experiments on the flow of rocks now being made at McGill University, by Frank D. Adams and John T. Nicholson: A paper presented to the Geol. Soc. Am., Montreal meeting, 1897. (Summary in Science, vol. vii, 1898, pp. 82, 83.)

critical temperature between those processes, it is probable that about 5,000 meters, under conditions of slow deformation, is a critical depth between the two processes.

However, it must be remembered that the mechanical work of deformation itself develops heat, which can only escape by conduction or convection. Therefore during mountain-making periods this temperature may have been attained much nearer the surface than 5,000 meters, and consequently recrystallization take place rapidly at depths much less than this.

Moreover, the temperature is raised by the presence of intrusive igneous rocks. The heat of the intrusives is conveyed to the adjacent rocks, both by conduction and by convection through water. Hence the presence of igneous rocks is favorable to recrystallization. This is so well known that it need not be dwelt upon. The broad zones of schists in which recrystallization is complete about the great batholiths, with schistosity everywhere parallel to the sides of the intrusives, are so numerous and well known in almost every country as to require no discussion. Well known American instances are the mica-schists and mica-gneisses about the Harney Peak granite of the Black Hills* and the zones of schists about the granite batholiths of western Massachusetts.

The identical character of the schists surrounding batholiths and those produced by regional dynamic action is explained by the foregoing pages. The necessary conditions for the production of recrystallized schists are movement under sufficient pressure, moderate temperature, and presence of water. These conditions are available in the two cases mentioned in different ways. In the case of the schists about batholiths the pressure is furnished by orogenic forces, and probably very largely by the intrusive itself. The heat is largely furnished by the igneous rock. If the intrusives are within the zone of fracture, water may readily gain access to the surrounding rocks.

Pressure and rapidity of deformation.—The less the pressure the more likely is the deformation to be accomplished by granulation. The greater the pressure the more likely is the deformation to be accomplished by recrystallization. The pressure increases with depth, with mechanical action, by igneous intrusions, and possibly by other causes.

To a certain point, the more rapid the deformation the more likely is the adjustment to be by granulation. The limit beyond which this does not apply is reached when the mechanical process develops sufficient heat, so that the readjustment is by recrystallization rather than by

*The pre-Cambrian rocks of the Black Hills, by C. R. Van Hise: Bull. Geol. Soc. Am., vol. i, 1890, pp. 206–210.

granulation. The slower the deformation the more likely is the readjustment to be by recrystallization.

ZONE OF COMBINED FRACTURE AND FLOWAGE

In the middle zone of combined fracture and flowage, the alterations may combine those of fracture and of flowage. Preparatory to understanding the phenomena in this zone, we may consider ourselves as seeing the phenomena of deformation in an imaginary rock of homogeneous character, composed of a single mineral which extends from the surface to an indefinite depth. Near the surface the rock is broken into blocks by faults and joints. There is no marked deformation of the individual particles, except in thin layers along the fractures. The textures of the rocks are for the most part preserved. Deeper down the fractures are closer together, and at sufficient depth the layers may be no thicker than leaves. Still deeper down every particle takes part in the deformation. This is the zone in which granulation is predominant, although with it there may be some recrystallization. Still deeper down recrystallization is more and more important, and when this process becomes dominant a coarsely crystalline schist is produced. It is therefore clear that there is every gradation between the phenomena of deformation of the various zones.

The transition above described for a single formation takes place at different depths for different formations and for different minerals of the same formation, and hence it is that in heterogeneous formations all of the phenomena discussed under both the zone of fracture and the zone of flowage occur close together.

At a given depth the stronger or less readily recrystallized rocks may be largely deformed by fracture, and the weaker or more readily recrystallized rocks be largely deformed by flowage. The result is that original textures and structures may be more or less preserved in the former, while in the adjacent layers original textures and structures may be entirely destroyed and the rocks become crystalline schists. It very often happens that the alternating beds which show original textures and structures and those in which they are obliterated may not be more than a few inches thick.

In the intermediate zone many of the beds are deformed by combined mass fractures and fractures of the individual mineral particles, so that in the same rock in which joints, faults, fissility, etcetera, and the alterations attending these phenomena occur, there are also found between the major fractures all grades of deformation by interior movement, from the earliest stages of peripheral granulation of the grains to complete granulation or recrystallization extending throughout the mineral particles. Thus we have all combinations of macroscopic and microscopic fractures and recrystallization.

In some places the intermediate zone of combined fracture and flowage is broad; in other places it is narrow. The phenomena of the zone may be seen in aqueous and igneous rocks alike. Many illustrations of each might be given.

As typical cases of sedimentary formations altered in the zone of combined fracture and flowage may be mentioned the Wewe and Siamo slates of the Lower Marquette series, and the Goodrich quartzite and the eastern half of the Michigamme formation of the Upper Marquette series, of the Marquette district of Michigan.* Within these formations almost every one of the multifarious reactions described, both within the zone of fracture and the zone of flowage, and many others, are beautifully illustrated. Indeed, it was a study of these formations which first suggested to me the idea of a combination of the phenomena of different alterations near the surface and at depth, and the very great difference in the alterations which occur under mass static conditions and under mass dynamic conditions.

In Calaveras creek, a short distance below Calaveras valley, south of San Francisco, in the Coast ranges of California, are seen all stages of transition between a brecciated igneous rock and a crystalline schist. The first was deformed under conditions of spaced fractures. The second was deformed by granulation and recrystallization. In passing from the breccia to the schist one first finds about the blocks of igneous rock which have their characteristic textures, mere films of schist. Passing farther toward the schist, an intermediate stage is found, in which unmashed blocks lie in a schistose background or matrix. But a short distance from this place is the completely altered schist, in which no unmashed fragments remain.

Every stage of the transition is seen. The alterations within the blocks are those of mass static conditions or those of molecular dynamic action (pages 287–294). Within the films and layers of crystalline schists constituting the matrix in which the blocks rest and in the main mass of schist the alterations are those of mass dynamic action.

COMPARATIVE ENERGY REQUIRED FOR DEFORMATION IN THE THREE ZONES OF FRACTURE, FRACTURE AND FLOWAGE, AND FLOWAGE

The question of the amount of energy required to produce deformation in the zone of fracture, in the intermediate zone of fracture and flowage. and in the deep-seated zone of flowage is a matter of great importance.

* Mon. xxviii, cit.

The energy for rock deformation may be divided into two parts—energy for mechanical work and energy for chemical work. The mechanical work is of three kinds—(1) the subdivision of the rocks, (2) the transfer of the material in order to produce a changed form, and (3) the friction between the parts of the subdivided rocks during the transfer.

The most useful comparison as to the amount of energy spent in the three zones is upon the basis of average mass deformation. I mean by average mass deformations the strains necessary to change the shape of unit masses of rock in a nearly similar way, so that the exterior forms are practically the same. To illustrate: A cubic foot of rock may be supposed to be divided into 10 horizontal slices and sheared parallel to these slices, so as to produce, ignoring the minor corners, a roughly rhomboidal mass (figure 1). If instead of 10 slices there were 100 slices, the approximation to a rhomboidal mass would be closer; if a thousand, closer still, and so on, until the slices became of infinitesimal thickness, when the mass would be rhomboidal. In all of these strains the mass deformation averages about the same.

It is perfectly clear that in the case of this hypothetical deformation the amount of work in rupturing would be directly as the number of slices. The average mass deformation is substantially the same, and the energy required for change in form—or, in other words, for transfer of

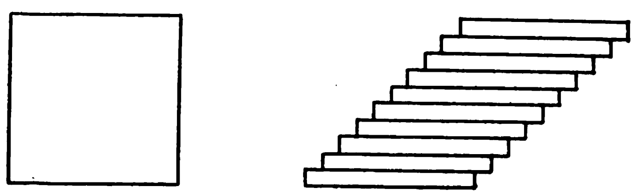

FIGURE 1.—*Illustrating average mass deformation*

material—is nearly constant. The total amount of differential movement or shear is practically the same in all cases, and therefore the friction is nearly constant. Hence in the case of the illustration the energy for the deformation is almost directly as the number of slices; but in the case of the crust of the earth, supposing the fracturing to become closer as depth increased, the energy required for a given mass deformation would increase with depth for two reasons: (1) More energy is required for the finer subdivision, and (2) the load increases with depth; and therefore the energy required to overcome friction also increases with depth. The energy required for the similar transfers of material remains practically the same at all depths.

It has already been seen that near the surface the dominant deformations are relatively wide-spaced joints and faults; that with increase of depth the spacing between the joints and faults decreases until the fracturing is that of fissility or of granulation.

It is therefore clear that the amount of energy required for fractures a considerable distance apart, such as prevail where joints or faults, or both, are the dominant deformations, is less than that required for the equivalent deeper-seated deformation, where the fractures are close together—as, for instance, in the case of fissility. Furthermore, it is clear that the amount of energy required for the slicing of fissility is much less than that required for granulation of the individual particles, for in the latter case a mass equivalent to a fissile leaf must be broken into a multitude of particles. Probably the ratio between the energy required for breaking a rock into joint or fault blocks near the surface and that required to produce fissile leaves deeper down is not greater than the ratio between the energy required to produce fissility and that required to produce granulation throughout at a still greater depth. No general ratio between the amount of energy spent in deformation by joints and faults and deformation by granulation can be given; but it is certain that the amount of energy used in the extreme cases of the latter may be indefinitely greater than that required for the former.

Since it is certain that in passing from the surface to considerable depth there is a passage from deformation by jointing or faulting, or both, to deformation by granulation, it is certain that to a depth of a number of thousand feet there is a steady and very rapid increase in the amount of energy required for a given mass deformation.

At sufficient depth, as has been seen, granulation is more and more replaced by recrystallization, and finally this process is dominant. It would be very interesting to know exactly the relative amounts of energy required for the two processes of granulation and recrystallization.

As already noted, the energy required for granulation is wholly mechanical and includes three factors: (1) that required for the subdivision of the rocks, (2) that required for transfer of material, and (3) that required to overcome friction.

The energy factors in recrystallization are four in number:

(1) Energy is continuously used in straining minerals during deformation; but it is impossible to determine the amount of straining which takes place, for evidence of the strain is continuously obliterated by solution and deposition. If the mechanical stresses did not continuously produce a state of strain, and thus disturb the equilibrium, it is probable that the rate of the process of solution and deposition would be very slow. It is this constant work in producing strain that keeps the process of recrystallization going.

(2) Energy is required for the transfers of materials by solution.

(3) Energy is required to overcome the viscosity of the solutions, or, stated in a different way, energy is required to overcome the friction of the free ions against the water during their movements.

(4) As a result of solution and deposition in the lower physico-chemical zone, the minerals produced are, upon the average, more compact than before the process. In so far as a more compact condition results energy is liberated. In the rare cases in which the minerals are equally compact before and after the process, as in the recrystallization of limestone, the energy of solution and deposition balances. In any case release from strain liberates energy.

We may now compare the energy demanded for each of the different factors in the two processes of granulation and recrystallization. The three factors entering into granulation are paralleled by the first three of the factors entering into recrystallization. (1) It appears probable that the energy required to produce granulation is greater than that required to produce a state of strain during recrystallization. (2) The energy required for the actual transfer of the material by granulation and by solution may be supposed to be the same. (3) The energy required to overcome friction during granulation is certainly vastly greater than the energy required to overcome the friction of the ions against the water during the transfer of the material. (4) As a result of the solution and redeposition, the minerals, upon the average, are changed to a more compact form, and by this reaction energy is liberated rather than consumed.

Therefore we may safely infer that the great excess of energy required in order to accomplish granulation, on account of the probably greater work of subdivision, the much greater work to overcome friction, and the energy usually released by the chemical reaction in recrystallization, render it reasonably certain that the energy required for granulation is certainly considerably greater, and may be several times greater than that required for recrystallization.

If one premises that when the conditions are such that either granulation or recrystallization might occur the process takes place which requires the less expenditure of energy, this furnishes additional support to the above conclusion, for wherever the conditions are such that recrystallization can replace granulation this occurs.

In the artificial deformation of limestone in the experiment performed by Adams the deformation was accomplished by granulation. When the deformation is made in the presence of water, as Adams proposes, it is probable, as already suggested (page 310), that the adjustment will be largely by recrystallization. It would be very interesting and important, if it were practicable, to compare the amount of work done upon the mass during deformation under these different conditions, for if this could be done it would be possible, at least in this case, to make some quantitative estimate of the relative energy demanded by deformation through granulation and through recrystallization. Doubtless this would be a difficult task. It would be necessary to separate the total work done in the machine into the parts which were required for the deformation of the rock mass and that required for the deformation of the surrounding iron, and in one case also to estimate the energy furnished by the water. If it were possible to make the determination, I anticipate from the analysis of the previous pages that the energy required for deformation through recrystallization would be much less than that required for deformation through granulation.

Of course, the question arises, in the cases of mountain-making, if less energy is required for recrystallization than for granulation, why the latter process occurs. The answer is plain. Recrystallization cannot occur except where there are the proper conditions of temperature and moisture. If the nucleus of the earth is shrinking, the outer crust must be reduced in size to accommodate itself to this nucleus. This implies crustal deformation which extends to the surface, and therefore to places where the conditions are not such that recrystallization can take place.

From the foregoing considerations, I believe that the amount of work done, in order to produce the same mass deformation of the rocks, increases to a certain depth and then decreases for a certain depth. How far down this decrease continues I am unable to conjecture, but believe it is probable that the decrease continues at least as deep as the zone in which the schists formed by recrystallization develop, and may continue much farther.

The deformation of this deep-seated zone may or may not require the elevation of the superincumbent mass. Where the superincumbent mass is not elevated it is therefore concluded that the energy required for deformation per unit mass is very much less than that required for granulation and may be less than that required to produce the spaced fractures which occur near the surface. Where the deformation is of the kind which requires the elevation of the superincumbent material, energy is needed not only to do interior work of deformation, but to elevate this material. Where these conditions obtain it may be possible that the amount of energy required to produce the deformation may steadily increase with depth on account of the energy required for lifting the load in addition to that required for the interior deformation.

So far as I know, the best region in America which illustrates all the phenomena from deformation by joints and widely spaced thrust faults to the interior deformation of recrystallization is that of the southern Appalachians. When in the Great Valley, we see that the Paleozoic rocks are little deformed except by joint-folds and thrust faults. As we pass east, deeper into the mountains, the joints and faults become closer together and are finally replaced by numerous closely distributed fractures. At the same time the rocks show more and more evidence of metamorphism—first by granulation, and second by recrystallization. In the cores of the mountains are schists and gneisses having well developed cleavage, and which have largely or completely recrystallized. In the valley the alterations affected but a small part of the mass of the rock. The deeper we went into the mountains the larger was the proportion of the material which was affected by the alterations, and in the crystalline schists in the core the entire mass was modified, both in a dynamic and a chemical way. It is clear in this passage that for a certain distance the amount of energy required for deformation per unit mass increased, but this tendency may have been reversed in the deepest-seated zone. However, since this latter zone is a region of uplift and the work required for the raising of the superincumbent strata must be added to that required for the interior deformation of the rocks which we now see, no positive statement can be made as to whether the total energy increased or decreased per unit mass in the deformation of the deeper-seated rocks.

The conclusions of the previous pages concerning the energy required for a given mass deformation at different depths gives a possible explanation of the concentration of superficial deformation found in mountain ranges. If the energy of deformation is less at the depth at which the crystalline schists develop than in more superficial belts, it is possible that the more rigid outer shell of the earth may shear over the nucleus in the zone at which the crystalline schists develop, the deformation being widely distributed. Such shearing for a considerable area may require less expenditure of energy than is demanded for the deformation of the rocks above; but during the earth movements, as a result of cooling and other changes,* the superficial material must certainly be deformed and and shortened, and at such places deformation is concentrated and mountain ranges are formed. This subject is, however, far removed from the scope of the present paper, and its discussion will be deferred to another time.

MEANING OF ROCK FLOWAGE

If the argument of the foregoing pages be true, the real meaning of rock flowage as deep as observation extends follows as a corollary.

* Estimates and causes of crustal shortening, by C. R. Van Hise: Journ. Geol., vol. vi, 1898, pp. 10–64.

In discussing the subject of rock flowage I shall summarize and to a certain extent repeat the substance of preceding parts of this paper. This seems necessary in order to bring the various ideas which concern rock flowage into their proper relations to one another as bearing upon that subject. I have previously maintained that the rocks within the scope of our observation which have been deformed at considerable depths were deformed by rock flowage.* However, I made no attempt to explain what actually occurred during the process. The foregoing discussion explains this to some extent at least.

I shall take as a typical example of rocks which have been deformed in the zone of flow those laminated crystalline schists the mineral particles of which now show slight or no strain (plate 19, figure 2); for it is evident that these are the rocks which have nearly perfectly accommodated themselves to the deformation through which they have passed. The accommodation, as already explained, is accomplished by continuous solution and deposition, or by continuous recrystallization. While the adjustment during deformation at any moment was nearly as complete as though the rock were a magma, and while it nowhere shows even a microscopic space, it is evident that the flowage is wholly different from that of a liquid. At no time was the rock a liquid. On the contrary, it was at all times almost wholly a crystalline solid. At no time was more than an almost inappreciable fraction of it in a liquid form—that is, dissolved in water—yet at all times it was adjusting itself by means of this small percentage of water contained in the capillary and subcapillary spaces, this being the medium of solution and recrystallization. In order that such a continuous process shall be adequate to explain rock flowage, it is necessary only that it shall be sufficiently rapid to keep pace with the deformation. One's first thought is probably that it is not possible that the process can be sufficiently rapid to account for the phenomena. However, the experiments of Barus upon the solution of glass give us a basis upon which we can make a quantitative calculation.

Barus † has shown that a temperature of 180° C. is critical so far as the solution of glass by water is concerned. At temperatures lower than this the rate of solution by water is very slow. However, at temperatures of 185° C. and above, solution and crystallization of the silicates of glass go on with astonishing rapidity. In Barus' experiment, as already seen, water dissolved a sufficient amount of glass and deposited the material as crystallized minerals to cause an apparent contraction of volume of the water amounting to 13 per cent of the water present in the

* Principles of North American pre-Cambrian Geology, by C. R. Van Hise: 16th Ann. Rept. U. S. Geol. Survey, pp. 593–595, 636–643.

† Compressibility of liquids, by C. Barus: Bull. U. S. Geol. Survey, no. 92, 1892, pp. 78–84.

capillary tubes in 42 minutes and 18 per cent in an hour. This shows that solution continued during the later stages of the experiment at about the same speed as during its earlier stages, for 13 : 42 about as 18 : 60. This is apparent when the first terms of the ratios are made 1, for the proportion then stands 1 : $3\frac{3}{13}$ about as 1 : $3\frac{1}{3}$. From this proportion it appears that the action was apparently slightly more rapid during the last few minutes. Reasons which may be suggested for an increased rate of action, supposing the pressure, temperature, and composition of the glass to remain constant, are (1) the smooth glass at the beginning of the process was less readily attacked than the roughened surface produced by solution ; (2) the roughening during the process gave the glass increased surface for action as the experiment continued. However, the apparent change of rate is so slight as to be possibly attributed to errors of observation.

During the experiment, unless hydrous minerals were produced, the water remained a constant quantity, and continued work. This could have been continued so long as the temperature and pressure were sufficient and glass was available for crystallization through solution, as a result of which the material is condensed. If no hydrated minerals are formed, there is no reason why a small amount of water cannot continue the process indefinitely.

If in this experiment we suppose the condensation of recrystallization to be 10 per cent, the amount of condensation in diabase in passing from the glassy to the crystalline conditlon, as shown by Barus,* this would mean (neglecting the condensation of the water) that in one hour, in order to have given an apparent volume contraction of 18 per cent, the water had dissolved 1.8 times its own volume of the glass, and deposited crystallized material with 10 per cent less volume. Therefore, for the water to dissolve a volume of glass equal to that of the water and deposit it in a crystallized form would require $33\frac{1}{3}$ minutes, or approximately one-half hour.

This illustrates the fact that the activity of water is amazing at a very moderate temperature, and one need not be surprised at its potency in the alteration of rocks deep below the surface of the earth. Temperatures higher than 180° C. exist at moderate depth, and therefore it is reasonable to suppose that a small amount of water may be the medium of rapid and most profound modification of the rocks.

We have already seen (pages 299, 300) that during the process of deformation the material, if not dissolved, may be strained even to the point of granulation by the mechanical processes; also it has been seen that, so far as strain occurs, or the particles are small, the minerals

* The contraction of molten rock, by C. Barus : Am. Journ. Sci., vol. 42, 1891, pp. 498, 499.

are in a state in which solution is easier than for unstrained or larger mineral particles. However, it is probable that the solution of such mineral particles and the deposition of the material in an unstrained crystallized condition is considerably slower than that of amorphous glass, for it cannot be supposed that the same amount of energy is potentialized in the mineral particles as in the glass. But the further the strain goes before fracture the more energy is potentialized, or if fractures occur smaller particles are produced. Moreover, the contained water is in small capillary or subcapillary spaces, and therefore a given volume is acting upon a much larger surface than in the capillary tubes used by Barus in his experiments. In so far as granulation occurs, the surface of action is still further increased. All these conditions are favorable to solution and redeposition; therefore the greater the straining and resultant granulation, the more rapid the process of recrystallization; hence in the deep-seated zone mechanical disintegration never gets far in advance of solution and redeposition (see pages 303–305).

If it be supposed in the capillary and subcapillary spaces within the rocks that the speed of solution of minerals is .1 of that of glass, water would dissolve its own volume of minerals and redeposit the material in about five hours. If the deep-seated rocks be supposed to contain 2 per cent of water by volume—that is, less than 1 per cent by weight—the entire mass of rocks might be recrystallized in about 250 hours, or little more than 10 days. The percentage of water premised is known to be lower than the amount ordinarily found in the crystalline schists (see page 308), and the rate hypothesized seems reasonable; but if this speed be decreased to .1 of that suggested or to .01 of that of glass, still the entire mass of the rocks might be dissolved and redeposited in about 100 days. Make the rate .1 of this or .001 of that of glass, and still recrystallization might be complete in about 1,000 days, or three years. If it be supposed that a mountain-making period occupied 150,000 years, and this is probably less rather than more than the time required for most mountain-making movements, during this period, at the slow rate suggested, the rocks could be recrystallized 50,000 times by 1 per cent of water, and this number certainly seems adequate to fulfill the requirement that at any given moment the crystalline rock shall exhibit but a slight strain effect.

Of course, it is not thought probable that any rock has completely recrystallized 50,000 times. Indeed, it is well known that many of the rocks in which recrystallization is complete, in so far as the finer particles are concerned, contain many larger particles which have not been completely recrystallized or even granulated. Perhaps one of the best instances of this is furnished by the schist-conglomerates. The typical schist-conglomerates contain a crystalline schist matrix, embedded in which are numerous large fragments. In many of these the matrix is completely recrystallized. The fragments, unlike the matrix, show important strains, which not infrequently pass to the point of partial granulation or recrystallization.

Indeed, to explain the phenomena in the case of crystalline schists which have been developed during a continuous process of deformation it does not seem necessary to suppose that complete recrystallization of all of the material is necessary.

If the case of a large grain of quartz or feldspar in a recrystallizing rock be taken, we may suppose the process to go on somewhat as follows: Because of the lack of homogeneity of the rock the stresses are irregularly distributed. At the most exposed places upon the mineral particles the conditions are favorable for solution, for the following reasons: The particle is there greatly strained, perhaps to the point of granulation, and, so far as strain exists or small granules are formed, these conditions are favorable to solution. At the places of great strain the material is therefore taken into solution and transported to the parts of the particles less strained. At such places the conditions are favorable to deposition, on account of the relatively large size of the residual original grains as compared with the granules. The mineral where least strained separates from the solution material like itself, attaching it to itself, in orientation with the core in an unstrained or little strained condition. The process of growth is analogous to that of mineral growth by secondary enlargement. The entire process is similar in several respects to that of the continuous solution and deposition of calcium carbonate in the chemical laboratory when water is passed through a layer of this material under pressure. Where the pressure is greatest in the upper part, the grains are taken into solution. At the place of escape, where the pressure is least, the material is deposited from solution, and the grains increase in size or grow.

During the deformation of the rocks this process of solution and deposition of a mineral particle is continuous.

If it be supposed to go on to a stage in which the original particle is one-half or one-third as thick as it was originally, it is not necessary to suppose that the central part of the mineral particle has been recrystallized. This is illustrated by figure 2. The spherical grain is supposed to have changed to the superimposed spheroidal grain. The common portion *C* may be an uncrystallized part of the old grain, but the material *A A* has been dissolved and added to the borders at *B B*. Corresponding to this explanation, some of the flat quartz grains of the mica-slates and mica-schists of the Black Hills of Dakota show residual cores.*

* Bull. Geol. Soc. Am., cit., p. 224.

During the process of recrystallization, at any given moment there will be the greatest shortening in the direction of greatest stress, greatest addition in the direction of least stress, and there may be shortening or addition in the direction of mean stress. Consequently the shape of the modified particle may be that which would be produced if a plastic grain were rolled out, the sides being confined in one direction, but with liberty to elongate in another direction; or it may be that which would be produced if a roundish cake of dough were pressed between two boards, and consequently elongated in all directions at right angles to the direction of greatest pressure; or, finally, the mean stress may approach so closely to the maximum stress that there is shortening in two directions and elongation in a single one only, in which case a fibrous structure is produced. However, from my study of the crystalline schists I am inclined to believe that shortening in one direction and unequal elongation in the directions at right angles to this is the most common case, though my thin sections give illustrations of all the cases.

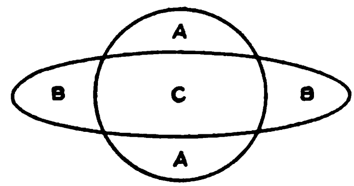

FIGURE 2.—*Possible relations of old and new grains of recrystallized rocks.*

In some cases the direction of greatest pressure varies within exceedingly short distances. The most common case of this is caused by the existence of large rigid particles, such as feldspar, garnet, or some other refractory mineral, which act as transmitters of pressure and deliver the stress nearly normal to themselves. In such cases the direction of greatest pressure adjacent to the rigid mineral particles is modified from point to point. The new particles there forming may curve about the rigid granules. This is beautifully illustrated by the flat, curved quartzes adjacent to feldspar in the quartz-porphyry described by Futterer (plate 19, figure 1, see page 301). In such a case the direction of orientation for the quartz, in order to adjust itself to the pressure, would continuously vary, and the flat individuals might show undulatory extinction as originally developed without having been strained subsequently.

What is true of one mineral particle is true of all others, and therefore we conclude that, while recrystallization is constantly occurring in the deformation of rocks, at any time the majority of the mineral particles retain their integrity and are nuclei which at any moment orient the material being deposited. In many crystalline schists evidence may be seen that this has happened. The old mineral particles, represented by the cores, may have been slightly altered, and in consequence of this may be discriminated from the freshly added material, or the cores may show a border of iron oxide or other mineral, or the old and new material may have slightly different compositions, and this be discovered by a difference in the color, refraction, extinction, or in some other way. Finally, all of the old mineral particles may be regenerated or recrystallized.

Therefore a given portion of a definite mineral particle in a crystalline schist may not have been recrystallized at all, or, on the other hand, may have recrystallized several or many times. It is believed that ordinarily the recrystallization is far advanced or complete for all parts of a typical schist, although this is far from the case in the semicrystalline schists or imperfectly schistose rocks.

Of course, in this rearrangement it is not supposed that the identical molecules which are taken from the more severely stressed parts of a grain are necessarily deposited at the places of less stress upon the grain. Undoubtedly there is great interchange of material between the particles by means of the solutions. It is, however, thought probable that in many cases of deep-seated deformation, where the passage of solutions is difficult and slow, that much of the identical material which is taken from a grain at one place is added to it at another place.

When new individuals are produced in any way, as by granulation or by the deposition of new mineral particles, perhaps as different species from any originally in the rock, they are subject to the same laws as the original mineral particles. Many have a tendency to form with similar crystallographic orientation. However, it is only rarely that the orientation of the particles of a given mineral approximates exactness. One mineral—for instance, mica—may be well oriented, whereas such minerals as quartz or calcite may not be oriented.

In proportion as the minerals readily respond to the forces of recrystallization or are mobile, they do not gain or retain regularity of arrangement. After mass movement has ceased the temperature may be sufficiently high and the heat be held for a sufficient time, so that the solutions may completely recrystallize the minerals under mass static conditions, and therefore orientation may be lost. In proportion as minerals do not readily recrystallize or stubbornly resist the force of recrystallization, the minerals once oriented retain their regularity of arrangement.

The most mobile of the important minerals is calcite. Quartz is also somewhat mobile. Therefore these minerals in marble and in recrystallized quartzite frequently lack regularity of arrangement. However, in some cases even calcite may show well developed, similar crystallographic orientation. The usual almost complete lack of regularity for calcite is illustrated by most of the marbles from the Laurentide mountains to Alabama. The complete recrystallization of quartz to a coarse granolitic textured rock, the individuals wholly lacking orientation, is illustrated by the quartzites of the Wausau district of central Wisconsin.

In the process of recrystallization of rocks it is not supposed that every large mineral particle retains a nucleus for lateral growth; indeed, it is certain that some particles of a mineral may retain the modified integrity above described in a rock in which other particles of the mineral may be wholly destroyed. While as yet it has not been fully worked out, it is believed that orientation of the mineral particles in reference to the varying stresses may have an influence upon their preservation. If the original particles happen to be in such positions as they would develop as authigenic minerals under the differential stresses, this is believed to be favorable to the preservation of their nuclei and to lateral growth. In proportion as the orientation of the particles is removed from such positions, it is believed that the mineral particles are likely to be destroyed. The effect of orientation with reference to the principal stresses upon the persistence of a given particle is probably great in proportion as the mineral has a tendency to be influenced in its crystallographic orientation by the stress differences which exist during deformation. To illustrate: The position of the crystallographic axes in reference to the greatest pressure in mica and feldspar, which show a marked tendency to similar orientation, would be a more important factor in their preservation than in quartz, which only rarely shows similar orientation.*

In the foregoing non-rotational distortion has been assumed. In case the deformation includes a rotational element, there would be no discoverable difference in the crystalline schist produced; † but during the deformation and recrystallization each of the particles would be similarly rotated, as well as flattened or recrystallized, or both, and consequently the direction of shortening and elongation might momentarily change.

Of course, in proportion as the conditions are unfavorable for recrystallization—that is, as mineral particles are refractory, as they are coarse-grained, as the deformation is slight but rapid, as the depth is little, as the temperature is low, as the water content is small—residual strain or mechanical granulation will occur instead of recrystallization. This is sufficiently evident without further explanation, from the discussion already given (see pages 305–312).

It is therefore concluded from the foregoing that rock flowage, as deep as observation extends, is plastic deformation through continuous solution and deposition, or, in other words, recrystallization. During the adjustment all or only a part of the material may have passed through this change. However, if a matrix, plastic by recrystallization, be filled with rigid granules which are not recrystallized, the whole mass may be

* Principles, cit., p. 635.

† Ibid., p. 638.

deformed by true flowage of the matrix and by slipping or shearing readjustment of the granules. So far as the average mass deformation is concerned, the result is substantially the same as though each rigid granule had not acted as a unit. Indeed, the same average mass deformation may be accomplished wholly by granulation and welding, as in Adams' experiments (see page 310); but it may, perhaps, be doubted whether this is ever strictly the case with rocks in nature, for some small amount of water is always present, and probably, even in the cases of apparent perfect granulation, some degree of solution and recrystallization from solution has occurred. In the case of the imperfect crystalline schists, which are very widespread rocks, the adjustment to the new form is accomplished in part by the process of differential movement of rigid granules and in part by solution and redeposition. It is only in the case of the typical granulated rocks that we can suppose that the process of deformation is mainly accomplished by the movement of the solid particles over one another, and it is only in the perfect crystalline schists that we can suppose that the deformation is accomplished almost wholly by recrystallization.

Nothing is said by the foregoing conclusions as to the condition of the material below the zone of the crystalline schists or the meaning of the flowage of such material.

The conclusions of the foregoing pages show clearly the meaning of rock cleavage. I have already held that this structure is largely due to the similar crystallographic orientation of numerous mineral particles, and especially those which are authigenic,* and therefore that rock cleavage is a capacity to part largely due to the actual cleavage of the similarly oriented mineral particles. As the cleavage of mineral particles has long been known to be a molecular structure, it follows that the cleavage of rocks is also largely a molecular structure. I have also explained that the similar crystallographic orientation is frequently, perhaps usually, accompanied by an arrangement of the mineral particles with their longer diameters in the same plane as the cleavage, and that this dimensional arrangement is a factor in rock cleavage, although one of probably less importance in most cases than that of the crystallographic orientation of the mineral particles.

RECRYSTALLIZATION AND AQUEO-IGNEOUS FUSION

It has been held by Mallet † and by others that the interior motions of mass dynamic action are sufficient to produce aqueo-igneous fusion,

* Loc. cit., pp. 633, 635.

† Volcanic energy; an attempt to develop its true and cosmical relations, by Robert Mallet: Phil. Trans. Roy. Soc., London, vol. 163, 1873, pp. 147–227.

and that such supposed fused material is the source of molten material for volcanoes. Mallet supposes that the material is mechanically divided so fine that a sufficient amount of heat is developed to fuse the particles. However, he does not tell how fine this must be. although he speaks of reducing a rock to an absolute powder. What is meant by an absolute powder is not apparent, but one might suppose it means a powder the particles of which are of molecular size.

It is apparent that the conclusions of the foregoing paper have an important bearing upon the hypothesis of aqueo-igneous fusion. It appears that if water is present when the material, as a result of the mechanical subdivision or for any other cause, reaches the very moderate temperature of 180° C., the adjustment is accomplished mainly by recrystallization, and that fusion is not necessary to account for the plasticity of the rocks. Probably a much higher temperature is required for aqueo-igneous fusion than for recrystallization. Barus* has failed to secure aqueo-igneous fusion at a temperature of 600° C., and at temperatures much lower than this it is certain that recrystallization of the rocks goes on very rapidly.

So far as the typical crystalline schists themselves are concerned, it is certain that they are not the products of aqueo-igneous fusion. They have peculiar textures characteristic of themselves, which are wholly unlike textures of unmodified sedimentary rocks, and unlike those which are known invariably to appear in rocks which have crystallized from a magma, however the magma has been produced. Every magma crystallizes according to the laws of magmas, and produces textures which are characteristic of such crystallization, and these are widely different from those of the crystalline schists.

It does not follow from the foregoing that the deeply buried rocks, including the crystalline schists themselves, may not become modified or even fused by contact with igneous intrusives. Indeed, I have held in another place that there are all gradations from water solutions to true magma;† but in proportion as the condition of the material approaches that of a magma, the textures produced approach those of igneous rocks. In some regions rocks occur showing remarkable combinations of textures characteristic of the clastic rocks, crystalline schists, and the igneous rocks. The consideration of such rocks must be deferred for the full paper from which the present article is adapted.

So far as my own observation goes, the phenomena which might be called aqueo-igneous fusion are generally local, and in connection with great intrusive masses such as batholiths; but in some great areas the

* C. Barus: 14th Ann. Rept., U. S. Geol. Survey, pt. 1, 1893, pp. 161, 162.
† Principles, cit., pp. 686–688.

intrusive material is so abundant and widespread, and its metamorphosing effects through water and magma in various proportions so profound, that the phenomena may be said to be regional.

SUMMARY OF CONCLUSIONS

The foregoing paper is adapted from a treatise. Notwithstanding my endeavors to make the paper short and simple, I find it has become somewhat complex, because it has been necessary to make many qualifications to the simple, general propositions. I here repeat some of the more fundamental principles stripped of qualification:

(1) The chemical alterations which rocks undergo vary greatly under different conditions. The more important of these variable conditions are water content, temperature, pressure, and movement.

(2) The outer part of the earth, of which we have definite knowledge, may be divided into two physico-chemical zones. In the upper of these the reactions take place with the expansion of volume and with the liberation of heat, as end results. In the lower the reactions take place with contraction of volume and with the absorption of heat, as end results. Some of the more important reactions in the upper zone are hydration, oxidation, and carbonation; some of the more important reactions in the lower zone are dehydration, sulphidation, and silication.

(3) The alterations under mass static conditions preserve previous textures and structures, but may go so far as to completely recrystallize the rocks. The alterations under mass dynamic conditions are different in the zone of fracture and the zone of flow. In the former the rocks are broken into fragments, and the alterations of the fragments are those of mass static conditions. In the zone of flow the alterations obliterate previous textures and structures and produce crystalline schists which have characteristic textures and structures.

(4) Rock flow is partly accomplished through mechanical strains, but mainly through continuous solution and deposition of the material of the rocks by the agency of the contained water. During the flow the rock is at all times almost wholly a solid, yet it responds like a plastic body to deformation without loss of its crystalline character because of the continuous adaptation of the mineral particles, while in large part retaining their integrity, to new forms by recrystallization.

(5) The energy required to produce a given mass deformation increases downward to the bottom of the belt of granulation. In the zone of flow by recrystallization the energy required to produce a given mass deformation is less, probably much less, than that in the lower part of the zone of fracture.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 9, PP. 329-342, PLS. 20-23 MAY 24, 1898

OMPHALOPHLOIOS, A NEW LEPIDODENDROID TYPE*

BY DAVID WHITE

(*Read before the Society December 29, 1897*)

CONTENTS

INTRODUCTION

Among the extensive collections from the Des Moines series, or Lower Coal Measures, of Missouri, sent during the last few years to the United States National Museum or the United States Geological Survey,† is a series of specimens which throw much interesting light on the unique and somewhat problematic species described by Professor Lesquereux as *Lepidodendron cyclostigma*.‡

Pitcher's coal mine, in Henry county, the source of most of the new material, seems, as indicated both by the associated species and by the matrix, to have been the source of the types of the original species, now numbers 5501 and 5502 of the Lacoe collection in the National Museum. In any event it is certain, as is shown by the records and labels, that the fossils described by Lesquereux came from the same vicinity. The species has not been found elsewhere.

Since the recently acquired material includes examples exhibiting many new characters and features, whose interpretation is subject to differences of opinion, as well as a remarkable variation in the forms of

* Published by permission of the Director of the U. S. Geological Survey.

† Collections forwarded by Dr J. H. Britts, Clinton, Mo.; by the U. S. Geological Survey, through Dr W. P. Jenney, now of Deadwood, S. Dak., and Mr Gilbert Van Ingen, now curator of the Geological Museum, Columbia University, New York.

‡ Coal Flora, ii, 1880, p. 394, pl. lxii, fig. 5.

cortical impression, the important specimens will be described somewhat in detail, in order to present for future consideration all the evidence at hand as to the organs or appendages of the tree, and its systematic position. It is unfortunate that in this, as well as in most other peculiarly American types of Carboniferous plants, no material is at hand to show the internal organization of the tree, which is represented only by somewhat flattened casts of trunks and branches, or by cortical impressions revealing only superficial details.

Detailed Description of Originals of Lepidodendron cyclostigma

The bolsters of these compressed trunks are, as was stated by Lesquereux, variable in form as well as size. Illustrations of these varying forms, which sometimes suggest the *Lepidodendron clypeatum* of Lesquereux,* are seen in plate 20 and plate 21, figure 4, and plate 22, figures 2 and 3. The fragmental impression, a portion of which is seen in the first plate, is 31 centimeters in length and 13 centimeters in width, the entire breadth of the trunk being unknown. It is probable, however, that some of the trunks of this species grew to a considerable diameter. The figured fragment shows the impression or mold, over most of which the outer very thin cortex or epidermis still adheres. Nevertheless, that phase in which the bolsters are represented at their longest and in their more distinctly Lepidodendroid aspect is well seen, the fine separative lines of the rhomboidal, acute bolsters being clear. while the general features of the subtriangular or somewhat circular central convex areas, which, as we shall see, represent large compressed, roundish bosses, are in agreement with the original figured by Lesquereux.† It will be observed that the bolsters are low, rounded, and destitute of keel or caudal ornamentation either above or below the scar; that the central convex area, as compressed, varies from round to more or less distinctly triangular, and that the boundary of the latter is often a sharp, clear furrow, from the lateral angles of which short, quickly vanishing lines pass outward toward the curved bolster margin, which they fail to reach. Other compressed specimens, mostly impressions, to which reference will be made, show the great variability in the aspect of these central areas. The photograph of the example under consideration fails to show a punctiform mammilla situated near the center of the convex area or but a very little nearer the lower border. This, which we may temporarily designate as the central trace, is visible to the unaided eye, as are also, in a few instances, two rather indefinite, rounded, low, vertical grooves crossing

*Geol. Penna., ii, 2, p. 875, pl. xv, fig. 5; pl. xvi, fig. 7. Coal Flora, ii, p. 380, pl. lxiv, fig. 16.
†Coal Flora, Atlas, pl. lxii, fig. 5; no. 5501 of the Lacoe collection, U. S. N. M.

the central area, one on either side of the central trace. The figure of this specimen is so placed on the plate that the central, obscurely subtriangular area comes generally at a little above the middle. Thus the transverse side, which is seen in many cases either to be crescentic or to contain a very obtuse angle, is made to constitute the base. This arrangement, which seems to conform with that of figures 1 and 2, plate 22, is made largely for the sake of preserving the morphologic similarity of the bolsters of this tree with those of the conventional type of *Lepidodendron* as represented, for example, in *L. clypeatum*. I confess, however, a lack of assurance as to the actual attitude of some of the stems. I have attempted to make them conform in position to other better preserved fragments, the orientation of which will be discussed farther on

In the comparison of the trunks from Missouri with the Lepidodendroid type, the reader will recall that in the typical *Lepidodendron* the surface of the cortex, which comprises the bulk of the trunk, is marked by rhomboid or fusiform, more or less protuberant leaf-base cushions or "bolsters," usually elongated and acute longitudinally, rounded laterally, compactly arranged in a complicated system of spirals. Near or above the middle of the bolster is a transversely rhomboidal cicatrix, variable in size and form, the scar left by the deciduous leaf. This "leaf scar" contains a central and two lateral punctiform traces or cicatricules, the central being the cross-section of the midrib or nerve of the leaf. The sometimes oval, lateral traces have been shown by Potonié to represent cross-sections of large-celled, lacunose, parenchymatous tracts considered as transpiratory. The latter reach the epidermis in two oblique, oblong mammillæ or "appendages," one on either side of the median line, just below the lower margin of the leaf scar. The two appendages have also been interpreted by various paleobotanists as glandular or other orifices in the leaf base. On the median line of the bolster, above the leaf scar, are two small deltoid depressions. The lower, close above the leaf scar, is believed by many to correspond to the ligular attachment in *Selaginella*, while, in continuation of the homology, the other deltoid depression, in the apex of the bolster, has been regarded by Stur and others as corresponding to the position of the sporophyll in *Selaginella* and *Isoetes*.

Passing now to the originals described by Lesquereux, we find that the figure given in the Coal Flora represents a small portion of an irregular fragment 27 centimeters in length and 15 centimeters in width. In this fragment, which, like the one described above, is a mold or impression, the Lepidodendroid form of the bolsters is clear. In a portion of the slab one end, presumably the lower, of the bolsters is slightly truncated by pressure in fossilization. The convex central areas or compressed central bosses are mostly ovate-triangular or ovate, as is shown in the original figure, though many are round and some are transversely oval. The lateral angles, as well as the short, vanishing, lateral furrows, are distinctly indicated in most cases, while generally the central trace in the roundish area is more or less clearly shown. This is also true where the outermost cortical tissue still adheres to the matrix, even in the area represented by the shaded portion in the original figure.

Another of the originals described by Lesquereux is a small slab, number 5502 of the Lacoe collection, representing, like the other, a mold or impression of the stem. In a portion of this fragment, too, we have bolsters and inside areas like those in the originally figured type, number 5501; but here we have also a variety of distortions, due to pressure, in which the central areas or compressed bosses often appear more than twice as wide as long, while in some cases they are partially covered on all sides by the infolded lateral areas about the flattened bosses. It may be noted in passing that the central areas in this fragment, photographed in plate 22, figure 3, are much broader in proportion to their altitude when the bolsters themselves are correspondingly dilated. In addition to these features, this specimen shows not only the central traces, but also in a few cases the obscure vertical furrows, which in several instances seem to unite below the upper margin of the central areas in a loop or long horseshoe, between the sides of which are the central traces. This character, as well as certain other more obscure details, will be considered in the description of the surface of the lately collected stems.

Description of Additional Specimens

Another incomplete slab, about 25 centimeters wide, showing the mold or external impression of the stem, is partially illustrated in plate 21, figure 3. In this specimen, chosen because it represents the more elongated bolsters with the central convex areas slightly displaced, we find in many of the latter the two vertical grooves, about 2 millimeters apart, passing across to the compressed boss and forming, as in the specimen just described, a loop or elongated horseshoe, within which the vascular trace is seen in all cases to lie. Occasionally a second trace is observed at the apparently open end of the horseshoe. The same interior characters are seen in Museum register 6030, another impression of a fragment with short squarish bolsters, illustrated in plate 22, figure 2.

The specimens described above are all impressions or molds of stems, in some of which the epidermis may have been wanting. We will now proceed to the consideration of several segments of stems on which the cortex is still preserved. The first of these, Museum register 6029, is a flattened branch, nearly the full width of which is seen in plate 21, figure

4. Here we see again a form of foreshortened, truncated bolster, comparable in form to that of *Lepidodendron clypeatum* Lx. Within the bolsters we have a very obtuse-angled prominence occupying a position at the base of the large boss. This transverse or flatly deltoid scar may be regarded as representing the horizontal side of the oval-triangular central area in the specimens previously noted. Within this angle, the thickened walls of which are suggestive of the leaf scar, we see the horseshoe-shaped loop including one or two small cicatrices. Indications of the more orbicular or prominent development of the large boss are seen at "a" on the cortex on the left, or in the partially decorticated area on the lower right.

A better understanding of this fragment, which has been removed from the left branch of the trunk illustrated in plate 22, figure 1, may, however, be reached by an inspection of the opposite side of the same specimen which is shown, enlarged to twice the natural proportions, in plate 23. The conditions seen on the surface of the cortex of this specimen are as follows: Within a broad, diagonally truncated bolster, suggestive of those of certain *Lepidodendra*, we have, as before, near the middle, a prominence in the form of a very obtuse angle, opening upward.* The protruding walls of this angle rise slightly and increase in thickness in approaching the center, where they in some instances form a very low deltoid area. The periphery of this transverse area exhibits for a distance of from 1.75 millimeters to 2.1 millimeters on either side of the center a rugose surface of carbonaceous matter, surrounded apparently by a line of separation. The area inclosed by this fractured carbonaceous rim can hardly be anything else than the leaf cicatrix; and I may add in this connection that none of the other specimens on which the outer tissues are preserved seems to show any other definite evidence of fracture or separation on the surface of the bolsters. From the lateral angles of these leaf scars, which are often slightly crescentic, pass narrow vanishing ridges which may lie in the same direction as the corresponding side of the cicatrix-"angle," or they may curve somewhat upward before vanishing in the border of the large boss which they help to define. The vanishing ridges and crescentic prolongations probably play an important part in preserving the roundish, distinct outline of the boss seen in the impressions earlier described. It must be remembered that on the cortex of the stems the interior surface of the large bosses is slightly concave. A resemblance to the impressions is seen in several of the bolsters in the abraded and partly decorticated portion on the

*The orientation of the figure is based on the plan of the fragment in the dichotomized trunk, pl. 22, fig. 1. The interpretation of this prominence as leaf scar, though somewhat tentative, preserves the Lepidodendroid analogy in the bolsters.

right in the figure. There is, however, when the entire cortex is preserved, no line of displacement nor break in the continuity of the epidermis beyond the leaf scar along this large subcircular or subtriangular boss that, in my judgment, can be construed as marking the separation of any appendage or organ.

Proceeding to the observation of the characters above and within the angle of the leaf scar, we note, as seen in the photographic enlargement, plate 23, an oval or slightly ovate area, the vertical diameter of which is about 2.5 millimeters, the transverse diameter being about 1.75 millimeters. The surface of this oval area is slightly raised as a boss above the concave surface within the large convex, rounded boss,* and is bordered in many cases by a very narrow, low, and sometimes obscure rim or by a narrow adjacent furrow. One or both of these conditions are possibly merely the result of pressure on the surface of the smaller oval boss, since there is occasionally seen hardly more than the sharply defined change of level in passing across its margin down to the large boss. I am inclined, however, to regard the narrow bordering rim, which is generally present, as normal. The lower end of this oval rim appears to become nearly contiguous to, if not actually united with the leaf scar; and at the lowest point it seems, in a few bolsters, to die out below and partly inclosing a small punctiform mammilla, which in one instance it appears to completely inclose. It is possible that this mammilla, which is in many cases discernible, should be regarded as belonging to the vascular trace of the leaf; but in the specimens before me it seems to be distinct from the leaf, if not in fact separated therefrom by a continuation of the oval rim. Within the oval boss just described is a small concave oval area, which is sometimes obscure in the lower part. This depression, the margin of which is nearly parallel to the outer border of the oval boss, the distance between being but little more than .5 millimeter, is deepest near the upper end, where it surrounds a minute bordered pit or umbilicate trace. The latter is the "trace" observed in the central area of the impressions and decorticated stems first described. The true vascular trace of the leaf is frequently defined in the carbon at the margin of the ovate-triangular concave areas representing the compressed large bosses in those specimens.

It remains also to note a minute mammilla, sometimes slightly depressed, occasionally seen a little above the upper margin of the large boss. This trace lies within a loop of the low round vertical ridges sometimes crossing the large boss. Though these ridges are sometimes clear in the molds or impressions, appearing as grooves or furrows, they are usually

* The interior oval-triangular area of the types first described.

rather obscure on the surface of the cortex, and may be entirely subcortical.

Concerning the cicatricial traces within the leaf scar itself, little can yet be said. What appears to be a vascular trace is observable in many instances; also certain obscure depressions in the bolster, which occupy the position of the respiratory appendages at the base of the leaf, seem to be present, but I am far from certain that these appearances may not really be due to accident or other causes.

In the slab, Museum register 5636, photographed in plate 22, figure 1, we have a large forked segment showing on the left the full width of the branch, the cast of the lower portion of which is still in place. The upper part or impression is the mold or counterpart of the fragment, plate 21, figure 4, just discussed. The similarity of the preservation on the lower left to that found in the lower right on the same slab is at once apparent. The middle portion of the branch on the right presents, however, the same characters as the lower portion of the other branch. In fact, we have at once on this specimen impressions of the large central convex boss of the type originally described as *Lepidodendron cyclostigma*, the quadrangular compressed bolsters, and the flattened bosses showing distinctly the details noted on the surface of the preserved stem. I am not absolutely certain whether in this slab we have a dichotomizing stem or trunk or whether possibly two trunks are superimposed. The facts that the bolsters below are in accordance as to direction; that those on the right of the angle change the direction of curve, as is natural at a dichotomy, and that I find no intercalated or separative zone or material, save numerous plications of the cortical tissues, make it seem most probable that the two branches are in actual union. Such plications are usually found in the angle of compressed Lepidodendroid stems, and they are especially to be looked for in those in which the cortical tissues are evidently spongy, and therefore subject to displacement under pressure.

The above notes cover the essential details of the species, so far as I can discern them in the compressed specimens before me; but mention should be made of a number of other peculiarities in this singular if not problematic tree.

To illustrate one of these I have partially represented in plate 21, figure 5, an impression or a mold to which the epidermis adheres. The margins of the outer boss appear to come nearly in contact with the margins of the upper part of the bolsters (although the latter can easily be traced to the apex) before curving inward and slightly downward, while becoming obscure, to meet the oval boss a little below its apex, thus producing a somewhat cordate effect. This aspect of the bolster and bosses is suprisingly like that figured as the type of *Lepidophloyos* *obcordatus* by Professor Lesquereux.* It is possible that both are referable to the same species. The oval bosses as well as the central mammillæ are very clear in this specimen.

Another fragment, a part of which is photographed in plate 21, figure 2, shows but a faint and fragmentary trace of the bolsters here and there. The surface is nearly flat, the larger bosses being nearly obliterated, only the leaf angle and the oval bosses being left in slight relief. Both the inner and the outer borders of the oval boss are defined, as is imperfectly seen in the photograph. This stem, the epidermis of which is in part preserved, is further ornamented by several large, shallow pits of two sorts. The larger ones in the lower portion of the specimen are nearly circular, and nearly equal in size the larger bosses of the other specimens. The details of their interiors are obscure. They show, however, traces of the two low, rounded, vertical ridges passing across them, with a central oval trace. These shallow, rounded pits, which are possibly caused by collapse of the large bosses, may conform with the convex areas in the bolsters in the types studied by Lesquereux, the vertical furrows and trace agreeing perhaps with the ridges and trace in 5502 of the Lacoe collection. The other form of depression seen in figure 2 is often elliptical, traversing vertically the obscurely indicated and wrinkled outline of the large boss. These elliptical pits are evidently coincident with the area and position of the vertical, rounded furrows seen in the round pits on the same fragments. The leaf angle and oval boss are wholly obscured. This elliptical or horseshoe appearance of the vertical ridges crossing the larger bosses, while never conspicuous in any of the specimens, is present and faintly visible in many of the bolsters of the fragment (figure 4 on plate 21). Although but little wider than the oval boss it is much longer, extending in this case a little beyond the large boss and including, as usual; the upper punctiform trace near the truncated upper margin of the bolster. In some respects the large, shallow depressions in this specimen are perhaps analogous to the abnormal or strobiliferous scars seen in some of the *Sigillariæ*.

Diagnosis of Omphalophloios cyclostigma

A résumé of the superficial characters preserved in the compressed cortex in this unique species is given in the following diagnosis:

Omphalophloios cyclostigma (Lx.).

Stems or trunks of considerable size, the larger covered by more or less clearly defined Lepidodendroid bolsters. Bolsters contiguous, sometimes partially obscure,

* Rept. Geol. Survey Illinois, ii, 1866, p. 457, pl. xli, fig. 1 (not figs. 2, 2a).

especially in the young or badly compressed branches, rhomboidal and acute, laterally rounded, or squarrose-rhomboidal, or often reduced and truncated by compression, normally somewhat prominent, convex-protrusive, without caudæ or corrugation, marked near the apex by a punctate mammilla, and surmounted over or at a little distance above the middle by a large interior, more or less roundish or ovate-triangular, slightly concave, prominent boss, at the lower crest of which is situated a transverse cicatrix, probably the leaf scar.

Central boss of the partially decorticated stem usually conspicuous, often appearing as an oval, slightly concave elevation, frequently apparently traversed by two somewhat indefinite vertical low ridges, and marked between the latter by a minute central trace; or, in the impressions, often appearing as convex and roundish or narrowed in either direction by the partial infolding of the surrounding tissue of the bolster in the course of compression.

Foliar cicatrices situated at or a little below the middle of the bolster, and on the lower border of the large boss or cushion, nearly one-half the width of the bolster, of very little altitude, slightly raised, angular or slightly crescentic below, the sides slightly upward inclined, sub-angular or broadly crescentic above, or flatly deltoid in the center, the lateral angles being continued for a distance as diminishing ridges which are either straight and vanishing short of the margin, or curving upward and blending with the base of the large central boss, within which, close above the foliar cicatrix, lies a smaller oval or slightly ovate boss containing an interior depression and punctiform trace.

Oval boss situated upon the large boss close within the ventral curve of the leaf scar, the longer, vertical axis being nearly one-half the altitude of the concave field of the larger boss, the horizontal diameter nearly two-thirds as long as the vertical, the lower end generally obscure, nearly or quite tangent to the leaf cicatrix, or possibly joined thereto, partly or wholly inclosing a minute punctiform mammilla which appears nearly contiguous to the foliar cicatrix and may be a part of the latter. Interior of the oval boss occupied by an oval depression, sometimes obscure, usually clearly defined, about .5 millimeter within the outer border of the boss, the interval being a flat oval zone, the upper and deeper end of the depression containing a minute umbilicate bordered trace. Vascular trace of the leaf apparently well developed, the lateral traces being obscure. Basal appendages either absent or very obscure.

Interpretation of the Parts

The difficult task of the interpretation of the details enumerated above and of the ascription to the structures of their appropriate functions is largely a matter of speculation and hypothetical analogy. I shall attempt only to prove some of the homologies between the trunk in hand and others of the Lepidodendroid type, hoping that other paleobotanists more familiar with the *Lycopodineæ*, both living and fossil, will furnish more accurate and valuable correlations.

The type of cortex before us appears to be one characterized superficially by rather strongly protuberant, non-carinate bolsters, exhibiting in outline the general variations characteristic of the Lepidodendroid type. These bolsters have large roundish or ovate triangular bosses, on which are placed the leaf scars and certain other structures. The large bosses were probably highly prominent in the uncompressed stems and were presumably composed, like the other portions of the bolster, largely of soft tissue that has proved very susceptible to distortion and variation under the conditions of compression. Their prominence and lack of support well accounts for their partial concealment beneath the folds of the adjacent portions of the bolsters in the flattened impressions, as well as for their displacement toward the sides of the bolsters in many cases. The degree of deformation of the bolsters in this trunk exceeds the greatest variations from pressure I have seen in the bolsters of *Lepidodendron Veltheimianum* Stb., or *L. clypeatum* Lx.

Pressure in a direction probably nearly vertical to the large boss evidently produced the rounded impressions described and figured from the originals by Lesquereux as *Lepidodendron cyclostigma*. From the lower and more prominent part of the large flattened boss two nearly parallel, obscurely defined, broad, rounded, perhaps subcortical, ridges pass upward across the boss, and apparently a little beyond it, then seem to unite in a horseshoe curve or rounded angle. Within the apex of this loop, and apparently a short distance above the boss, is situated a rarely visible punctiform trace. I am unable to state whether this long, obscure, vertical loop is closed at the base to form an ellipse, though it slightly affects that appearance in the pits figured in plate 21, figure 2. It may proceed on either side from the lateral wings of the leaf scar at the base of the boss. There is nothing on the specimens before me to indicate an attachment of any vegetative organ along its surface or margin.

Certain very important points as to the relations of the second or oval boss to the leaf scar remain to be determined. At present it is not definitely ascertained whether the oval boss, which in a few instances appears to be closed at the base and barely contiguous with the transversely angular or deltoid cicatrice which I have called the leaf scar, is actually distinct from that "scar" or whether it is organically connected therewith. The analogies with the other Paleozoic *Lycopodineæ*, especially some of the Sigillarioid types, would at first glance lead us to inquire as to whether this oval boss does not itself represent a part if not the whole of the foliar cicatrix. The evidence in support of such a supposition lies largely in the presence of the generally clear, narrow, very low marginal rim of the boss and its naturally suggestive similarity to the form of the cicatrices in some of the *Bothrodendra*. Continuing the parallel with the Bothrodendroid or Sigillarioid scar, it appears that in this case the trace at the upper end in the central oval depression may be the vascular trace, while, by reversing the position of the specimen, the punctiform trace, which now seems either close within or partly between the vanishing ends of the lower curves of the oval, might be correlated with the trace just above the foliar cicatrices in *Sigillaria* and *Bothrodendron*. On the other hand, in opposition to the above hypothesis, the interior details of the oval, the basal angular or deltoid scar, and the superior trace in the bolster, as well as the form of the bolster itself. seem to be arraigned. The oval boss comprises an outer zone about .5 millimeter in width inclosing an oval depression. I have found no traces within the latter except the umbilicate trace, generally near the upper end, and this shows on the cortex as a minute pit bordered by a raised carbonaceous rim. In the impressions this trace causes a minute projecting point. Next, the slightly raised transverse cicatrix at the base of the oval boss and on the lower edge of the large boss, showing a surface of separation, appears to be supplied with a vascular trace and occupies the position of a leaf in the Lepidodendroid bolster. There are in a few instances even slight, though quite uncertain and perhaps worthless, signs of the subfoliar appendages. Much depends on the relation of the oval boss to the transverse scars, which I have designated as leaf cicatrices, and these relations can perhaps be ascertained only by the discovery of additional material. On those bolsters the cortical tissue of which appears best preserved and intact the rim of the oval boss would seem in some cases, as shown in the photograph, plate 23, to be nearly, but not quite, tangential to the transverse scar, the punctiform trace being slightly within the outer oval boundary. In this matter the evidence of other bolsters would, however, seem somewhat conflicting. It should be remarked that in those bolsters in which the base of the oval is most clearly defined the vertical diameter of the transverse or leaf scar seems considerably foreshortened in the course of fossilization.

If it be found, as seems to be indicated in some instances, especially where the protruding leaf scar is abraded, that the rim of the oval boss is really in union by a narrow connection with what is here, perhaps erroneously, interpreted as the leaf scar, the conditions will be perhaps best satisfied by assuming that the oval boss was the seat of some expansion or unfamiliar structure on the ventral surface at the base of the leaf of which it would form a part. In such an arrangement the trace above the large boss might be the homologue of the so-called "ligule," or the "sporophyll" scar, while the small umbilicate trace in the central depression would constitute a new basis for speculative analogy. However, while far from conclusive, the signs at hand do not appear to favor that hypothesis.

Assuming that I am not mistaken in treating the transverse basal scar as proper to the leaf rather than as a mere fracture or abrasion, we would seem to have a cortex marked by prominently bossed Lepidodendroid bolsters, in the axils of whose leaves was situated either some organ or appendage attached to the oval boss, or else, as appears more probable, an oval plaque in the depression of which was a minute umbilicate trace. In accordance with such an hypothesis the punctiform trace at the upper margin of the leaf scar might be homologized with the "ligular" trace or pit of the typical Lepidodendron, while the umbilicate trace within the oval boss may be analogous to if not homologous with the so-called "sporophyll" in those stems.

Whatever the interpretation offered, the superficial characters of these stems seem to be quite different from those of any of the existing Lycopodineous genera. Consequently I propose for those trees with this type of embossed cortex the generic name *Omphalophloios*, though a diagnosis of the genus* of which *O. cyclostigma* is the type is postponed until the relations between the oval boss and the leaf cicatrix are more clearly demonstrated.

A specimen which I regard as representing a decorticated or *Knorria* state of this type strongly resembles the *Knorria* of *Bothrodendron*, to which genus ours is perhaps most closely allied.

Localities.—The originals described by Lesquereux are numbers 5501 and 5502 of the Lacoe collection, United States National Museum, "Clinton, Henry county, Missouri." Later accessions are from Pitcher's coal mine, lot 407, Museum register 5636, and lot 340. Deepwater, lot 408, Henry county, Missouri. The *Knorria* fragment is from Gilkerson's Ford, in the same county.

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*'Ομφαλος, the boss of a shield, + Φλοιος, bark.

EXPLANATION OF PLATES

Plate 20

Pitcher's coal mine, Henry county, Missouri. U. S. N. M. Reg. 6024.

Plate 21

Figure 1.—Branch. U. S. N. M. Reg. 6028.

Figure 2.—Fragment of larger branch, showing large oval scars. U. S. N. M. Reg. 6027. *2a*. Detail of bolster, enlarged.

Figure 3.—Impression of fragment of cortex. U. S. N. M. Reg. 6025.

Figure 4.—Portion of left branch of figure 1, plate 22. U. S. N. M. Reg. 6029.

Figure 5.—Impression of fragment of young tree, showing oval bosses. Collection of Dr J. H. Britts, Clinton, Missouri.

All specimens from Pitcher's coal mine, Henry county, Missouri.

Plate 22

Figure 1.—Fragment of trunk at point of dichotomy, showing bolsters, leaf scars, oval bosses, and impression made, at left, by fragment photographed in figure 4, plate 21; the back side enlarged in plate 23. U. S. N. M. Reg. 5636.

Figure 2.—Impression, with compressed Lepidodendroid bolsters. U. S. N. M. Reg. 6030.

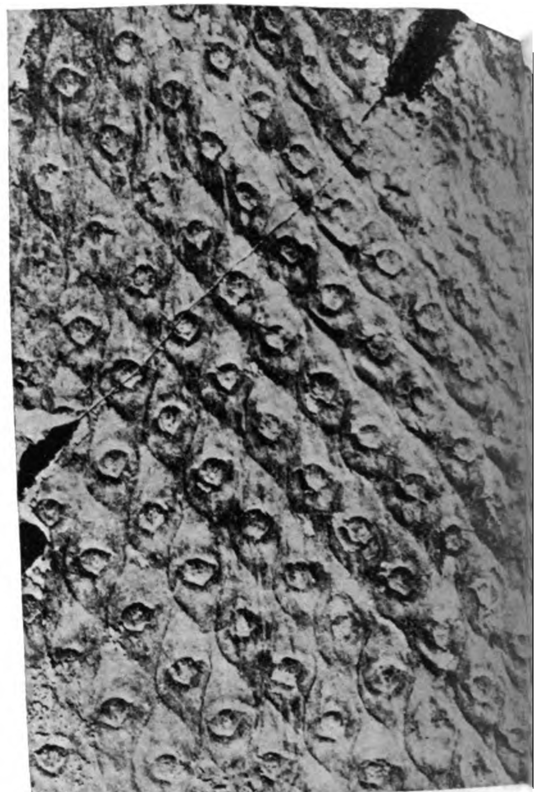
Figure 3.—Type of *Lepidodendron cyclostigma* Lx. U. S. N. M., Lacoe Coll., Reg. 5502. Henry county, Missouri.

Plate 23

Photographic enlargement of back of figure 4, plate 21, the impression of which is seen in the upper left of figure 1, plate 22. The un-retouched photograph shows the compressed and foreshortened Lepidodendroid bolsters, the fracture surface of the leaf scars, the smaller oval bosses, the central depression, and the contained mammillæ. U. S. N. M. Reg. 6029.

OMPHALOPHLOIOS CYCLOSTIGMA LX. SP. NATURAL SIZE

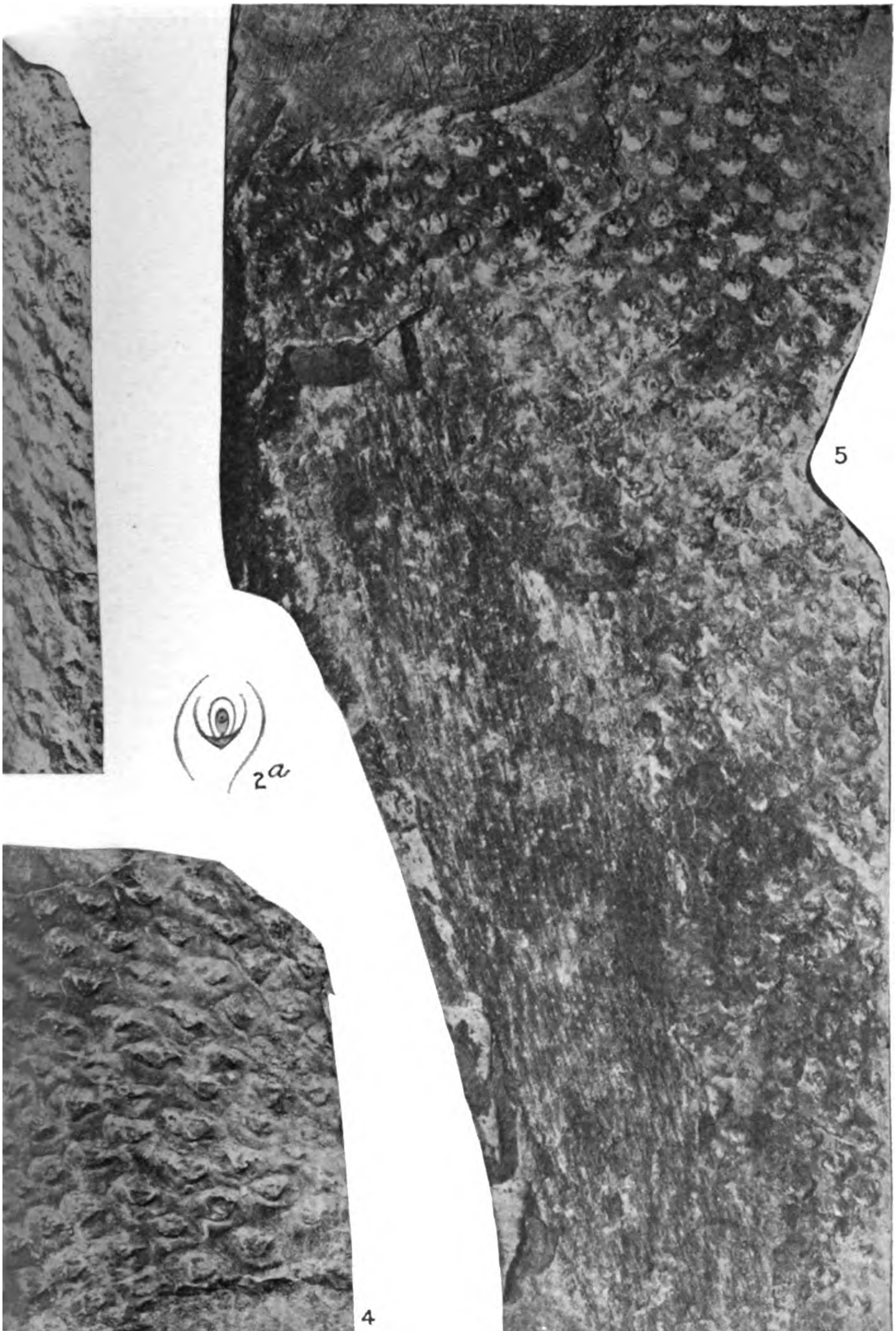
1



3

2

OMPHALOPHLOIOS CYCLOST



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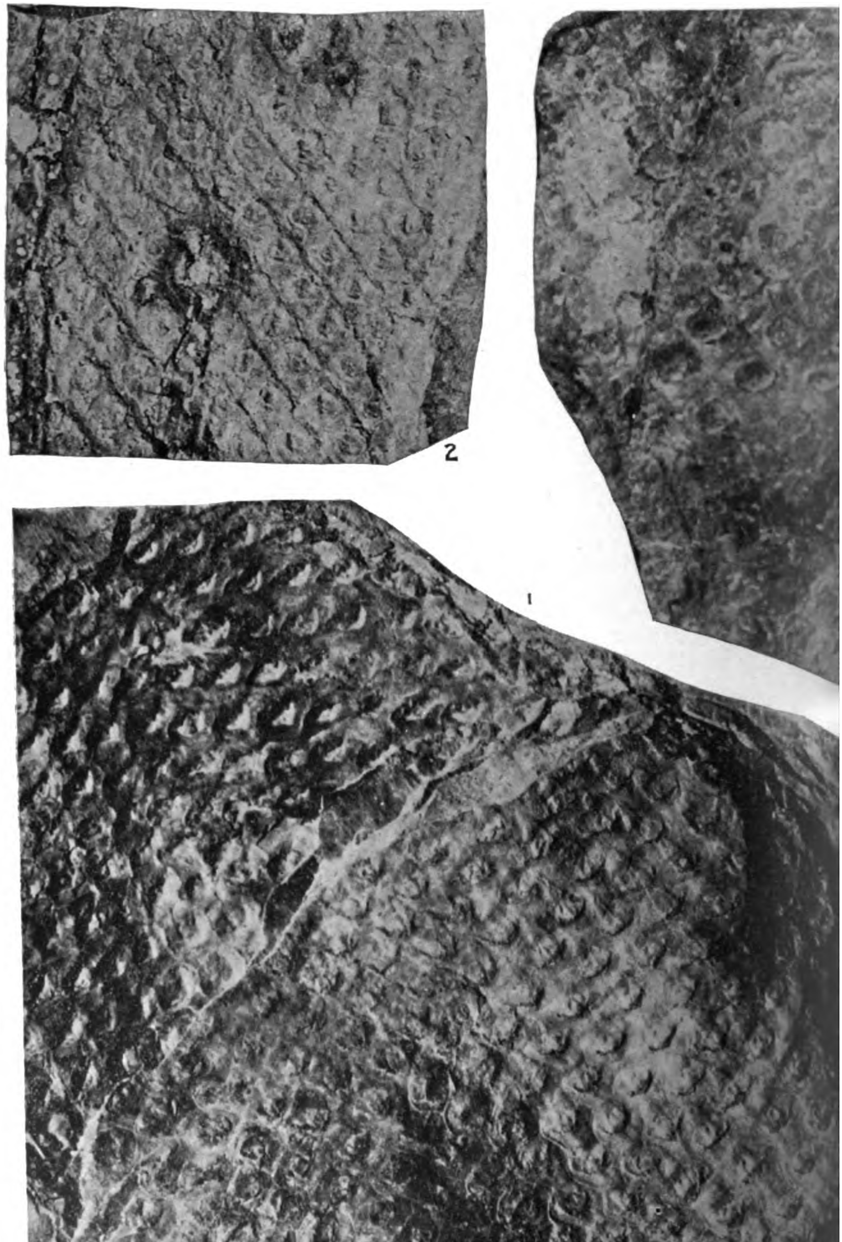
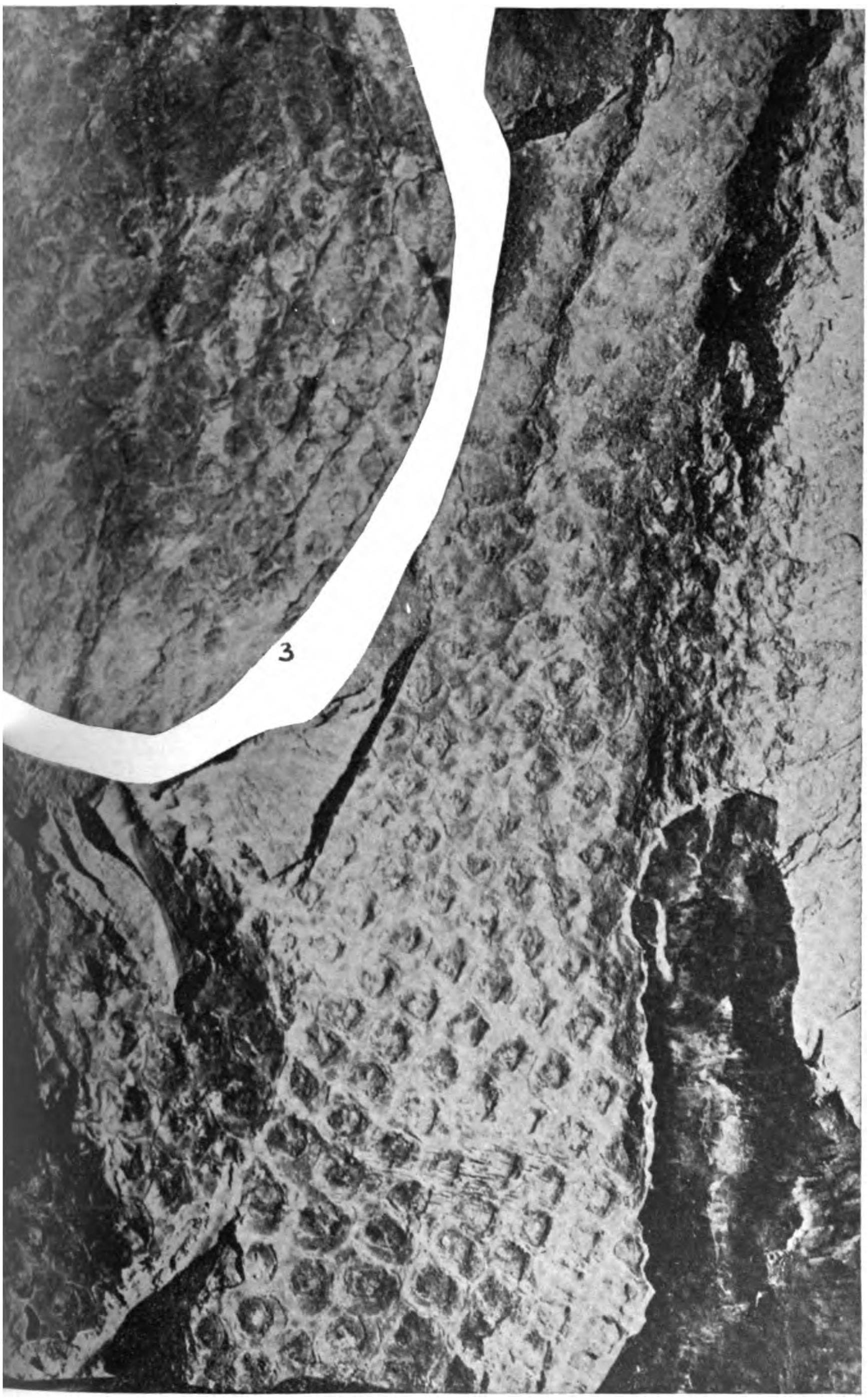
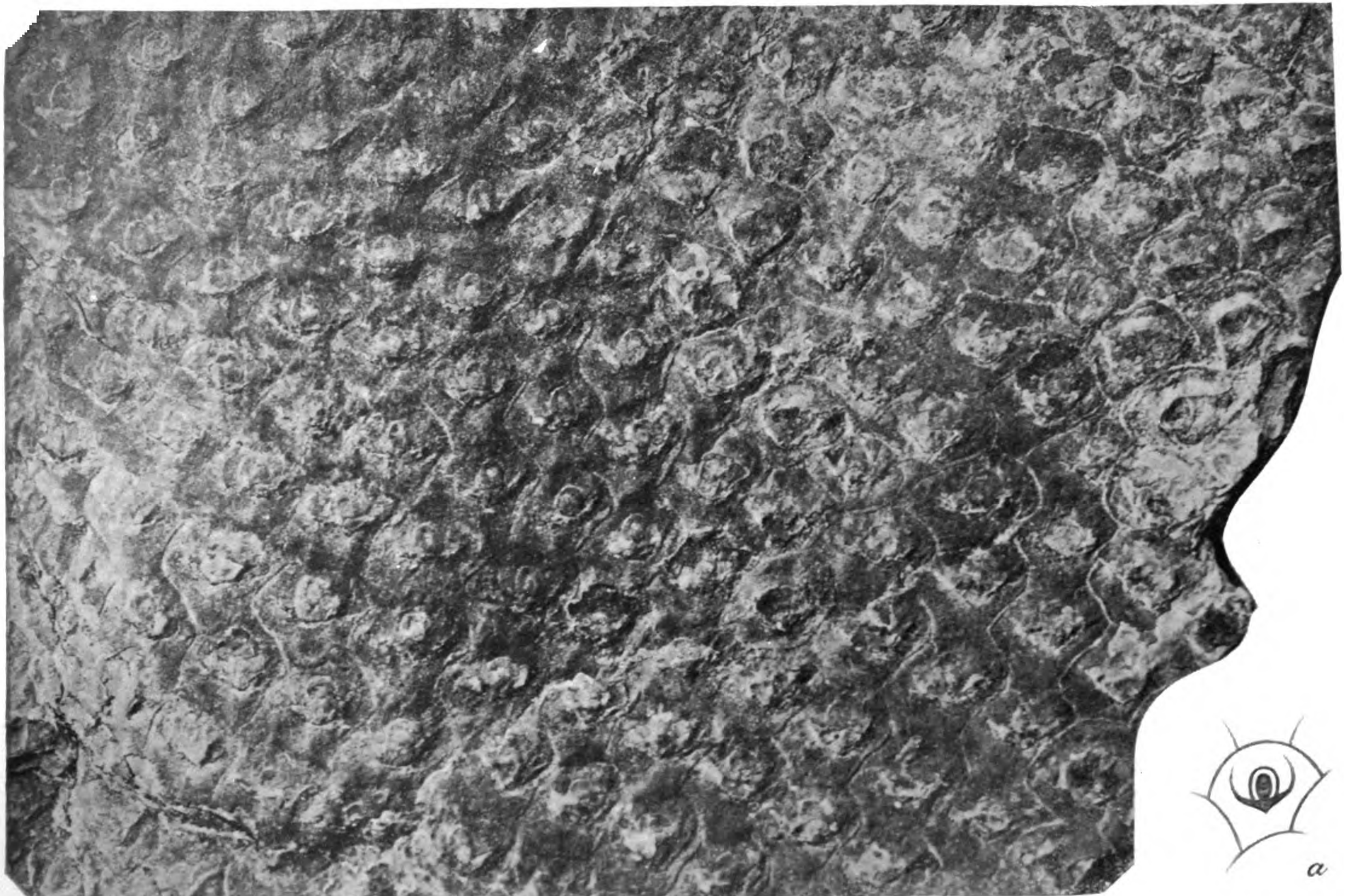


OMPHALOPHLOIOS CYCLO

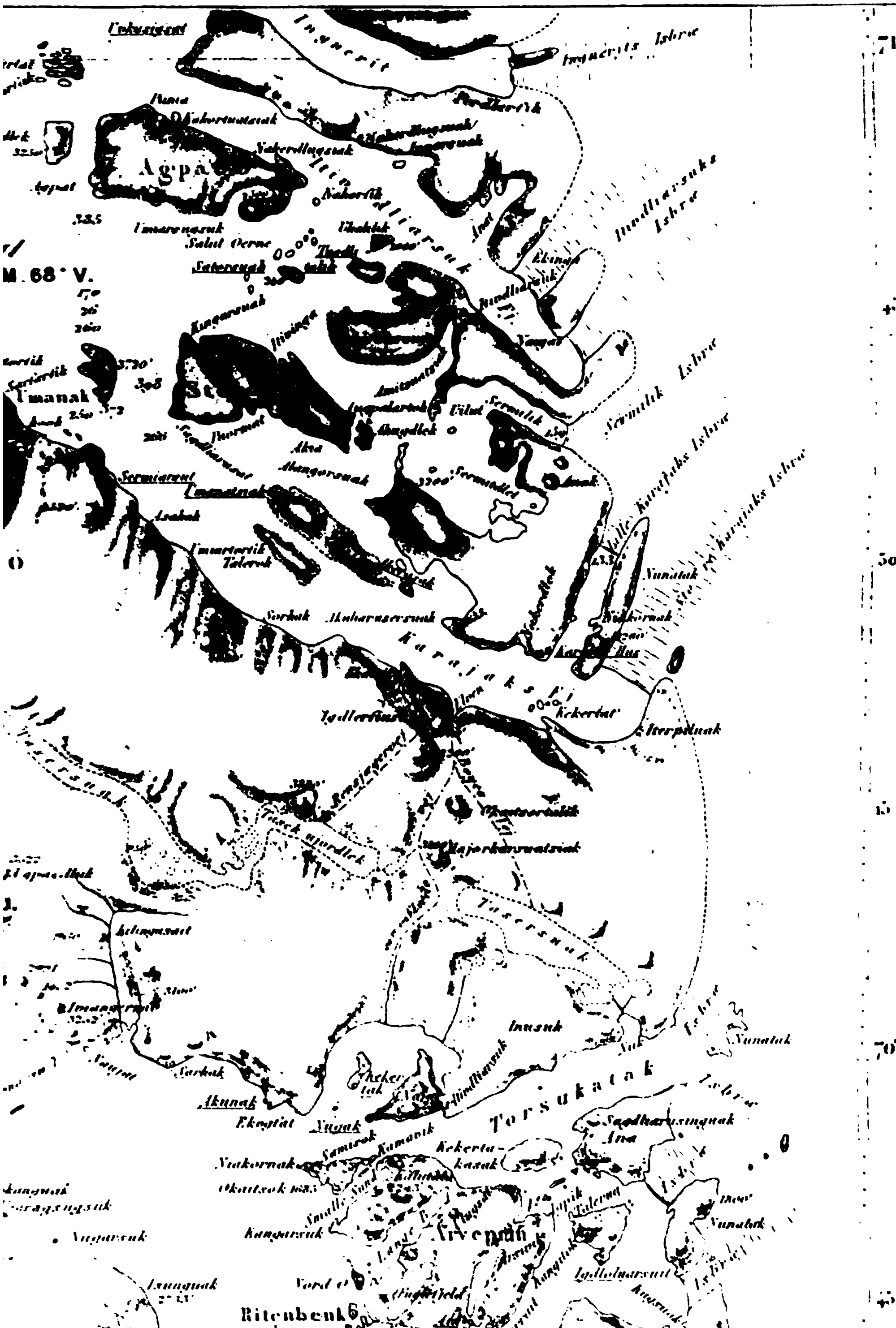


IGMA LX. SP. NATURAL SIZE



OMPHALOPHLOIOS CYCLOSTIGMA LX. SP. ENLARGED × 2

REGION OF NUGSUAK PENINSULA



WEST COAST OF GREENLAND

Reduced from Danish Official Map

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 9, PP. 343-368, PLS. 24-26 JUNE 21, 1898

CRETACEOUS SERIES OF THE WEST COAST OF GREENLAND*

BY DAVID WHITE AND CHARLES SCHUCHERT

(Read before the Society December 29, 1897)

CONTENTS

INTRODUCTION

The geological and paleontological work in Greenland which forms the basis for the following somewhat fragmentary notes was carried on under authorization of the United States National Museum in connection with the Peary Arctic Expedition of 1897. The chief object was to make collections of fossils from the type Cretaceous and Tertiary localities of Nugsuak (Noursoak) peninsula (plate 24) for comparison with those from the Potomac, Dakota, and other Cretaceous formations of North America; but, besides the collecting of geological and paleontological specimens, the writers were further charged with gathering living plants, insects, and mammals. Plans were matured for a field season of six weeks in Greenland, during which it was purposed to search the prin-

* Published with the permission of the Director of the U. S. National Museum.

cipal type localities in the Kome beds on the north side of Nugsuak peninsula and in the Atane, Patoot, and Tertiary series on the south coast.

After several delays, the expedition left Boston on the steam sealer *Hope* July 19, landing the writers on Umanak island on the evening of the 8th of August. On August 10, with native oarsmen, we left Umanak to begin our task at Kook. At noon on the 4th of September the homeward bound ship called for us at Atanikerdluk. From this it will be seen that 25 days only were available in Greenland for both travel and work.* Within that time we rowed about 150 miles, made 14 camps, and gathered fossils from 37 localities. It is thus evident that little time was left for stratigraphic studies or making varied natural history collections. However, satisfactory collections of both fossil and recent land plants, as well as a small quantity of miscellaneous material, were accumulated.†

Few lands within the Arctic circle have received more attention from geologists and paleontologists than the region including Disko island and the great Nugsuak peninsula. Danish administration officials, as well as explorers and naturalists of all nations, have collected from its phytiferous deposits to swell the volume of the Arctic fossil flora, while Brown,‡ Nordenskiold,§ and K. J. V. Steenstrup || have given especial attention to the stratigraphy. The history of earlier geological exploration in this region is given by the two first named authors. Investigations since their publications have been carried on almost exclusively by Steenstrup. The results are two relatively detailed geological maps by Hammer and Steenstrup ¶ and an interesting series of studies of the basalts and native irons.

General Geological Relations

The Cretaceous and Tertiary deposits of the west coast of Greenland are exposed at numerous places on the islands and peninsulas along the

* Of these but little over two days were lost on account of bad weather.

† The recent plants are now in process of elaboration by Mr C. L. Pollard, of the National Herbarium. The fossil plants have in part been examined by Dr F. H. Knowlton and the fossil invertebrates have received attention from Dr T. W. Stanton, both of the U. S. Geological Survey. The petrographic material is now in the hands of Dr George P. Merrill, of the U. S. National Museum.

‡ Robert Brown: Geological notes on the Noursoak peninsula, Disco island, and the country in the vicinity of Disco bay, North Greenland. Trans. Geol. Soc. Glasgow, vol. v, 1875, pp. 55–112, with geological map.

§ S. E. Nordenskiold: Account of an expedition to Greenland in the year 1870. Geol. Mag., vol. ix, 1872, pp. 289–306, 355–368, 409–427, 449–463, 516–524, pl. vii, map, pl. viii.

|| K. J. V. Steenstrup: Ueber die Lagerungsverhältnisse der Kohlen und Versteinerungen führenden Bildungen auf der Westküste von Grönland zwischen 69° 15′ und 72° 15′ n. Br. In Heer's Flora Fossilis Arctica, vii, 1883, pp. 228–250, with colored geological map. Bildrag til Kjendskab til de geognostiske og geographiske Forhold i en Del af Nord-Grönland. Meddelelser om Grönland, iv, 1893, pp. 173–243, with large colored geological map. See also Meddelelser, vol. v, 1893, pp. 1–42, 43–78, with geological map.

¶ Meddel. om Grönland, v, 1893. Heer, Fl. Foss. Arct., vii, 1883.

deeply indented coast within a zone, not over 75 miles from east to west, extending from latitude 69° 15′ to 72° 15′ north. The sedimentary terranes are probably not less than 3,500 feet in thickness. They rest on a very irregular, even hilly, floor of gneiss, granite, diorite, and old basalts, and they are covered almost throughout by apparently regularly horizontally bedded flows of Tertiary basalt. Although the latter has been subject to erosion to a great extent, it still retains a thickness of over 3,000 feet at a few points, while in the peak Kilertinguak it appears to exceed 4,000 feet. The clastic rocks have a light average dip to the westward on the south side of the peninsula, though locally they are highly variable in attitude as well as in thickness. The lowest sedimentary terranes lie below tide level between the old crystalline hillocks or knobs which rise here and there several hundred feet above tide, even far out in the interior of the sedimentary zone or belt, as it may for convenience be considered. It follows from this condition that the oldest sediments, probably Cretaceous in age, are below tide level.

The youngest Tertiary terranes are often interbedded with the basalts, while in certain areas both the Cretaceous and Tertiary deposits are cut at various angles by numerous, sometimes intersecting, dikes.

Nugsuak peninsula, the field of the writers' observations, lies somewhat obliquely between 69° 55′ and 70° 57′ north. From the nearest point between the Karajak fiord and the Torsukatak glacier at its base to the western extremity is about 90 miles, the width for nearly two-thirds of its extent being about 30 miles. The Cretaceous and Tertiary deposits constitute the western two-thirds of the peninsula, the Tertiary sediments continuing to near its western extremity. The interior of the peninsula is either covered by local ice caps or it is unexplored, so that, with the exception of Ifsorisok, an inland point near the western end of the peninsula, the Cretaceous and Tertiary have been seen only beneath the basalt along the coasts or along two short river valleys.

Of the three divisions of the Greenland Cretaceous established by Heer on paleontological evidence, the Kome or lowest series has hitherto been definitely recognized only along the greater portion of the north coast from Kook to Ekorgfat, no fossils of the Upper Cretaceous and Tertiary being found in this district,* although at Ujarartorsuak the sediments have been supposed to be 2.500 feet thick. Westward from Ekorgfat, as far as Iterdlak, the sedimentaries contain invertebrate fossils, which are regarded as probably of the age of the Middle (Atane) division of the Cretaceous. All the fossil plants found in this interval on the north coast, and consequently all the sedimentary terranes from Kook to Ekorgfat,

* Mention should be made of Tertiary fossiliferous morainal material on the surface of the glacier at Asakak, 10 miles east of Kook, as these are the only Tertiary fossils known on the north coast.

inclusive, were regarded by Heer as belonging to the Kome series. Nordenskiold, however, was disposed, on account of the great thickness of the series, to consider the higher Cretaceous and so-called Miocene as probably present.

PRINCIPAL FOSSILIFEROUS LOCALITIES OF THE NORTH SHORE OF NUGSUAK PENINSULA

As has been indicated above, most of the fossiliferous localities known on the north shore of the great Nugsuak peninsula have been supposed to lie within the Kome series. The most eastern exposure of the Cretaceous is at Kook (Kome), the typical locality of the Kome series, of the Lower Cretaceous of Greenland, correlated by Heer with the Urgonian of Europe. The occurrence of fossil plants at this place has long been known, the *Pecopteris borealis* described by Brongniart* and other species published by Goeppert† having been obtained at this place.

Kook.—The rocks in the vicinity of Kook consist of cream-colored, often shaly or laminated sandstones, alternating with thin beds in grouped series of dark shales. The sandstones are, as a rule, arkose, cream-colored, poorly cemented, and sometimes slightly conglomeratic, though mostly thin bedded and intercalated with the shales. The latter, varying from thin laminæ to scores of feet in thickness, are nearly always arenaceous, often with loose sand or arkose partings. Frequently the quantity of carbonaceous matter in the laminæ is so great as to render them combustible, and when the layers have some thickness they are described as coals; but it very rarely happens that the proportion of macerated vegetation is sufficiently great to fully justify its designation as coal or lignite.‡ In general the "coals" appear to predominate in three groups: *a*, within 200 feet of tide; *b*, 400 to 600 feet above tide; and *c*, above 800 feet above tide. The local variations in the stratigraphy were found to be so great as to give little value to detailed sections for comparison between points somewhat distant.

The Cretaceous series appears to extend without any essential or well marked lithological change to an altitude of 1,500 feet; at least no Tertiary fossils have yet been found in it. A short distance west of the Kook glacier the series shows in phytiferous beds at tide level beneath which other older beds probably lie between the gneiss hillocks. The dip of the strata as seen in the deep ravines varies from 5° to 15° coastward. The greatest dip is near the strand, decreasing, especially locally,

* Hist. Vég. Foss., i, 1831, p. 351.

† Ueber die Tertiärflora der Polargegenden. Abh. Schles. Gesell., 1861, 2, pp. 195–207.

‡ There is little regularity in the "coals" or in the sandstones, which are often lenticular or split. Frequently the coaly laminæ are separated by a few inches of cream-colored sand.

farther up the streams. Along the shore the dip is very slight, varying locally toward the east or the west.

Fossil plants were obtained (1) at about 90 feet above tide in the small ravine to the west of the glacial stream, (2) from the *Pinus crameri* beds on the shore about 100 yards west of the houseplace, (3) from the ravine next westward, at an elevation of 60 feet above tide, and (4) at about the same level in the next two ravines westward.

The plants collected near Kook include the following more or less common Kome species:

I. Kook, first ravine west of the glacial stream: *

Dicksonia bellidula Hr. Kp.
Sphenopteris lepida Hr. Kkps.
Asplenium boyeanum Hr. Ks.
Pecopteris andersoniana Hr. Kp.
Gleichenia rigida Hr. ? Kks.
Equisetum amissum Hr. Kkps.
Zamites globuliferus Hr. Ks.
Sequoia subulata Hr.

II. Kook, fourth ravine west of Kook glacier:

Adiatum formosum Hr. Ks.
Pteris frigida Hr. Kk.
Pecopteris borealis Brongn. Kks.
Gleichenia gieseckiana Hr. Kkps.
G. zippei (Corda) Hr. Kkps.
G. longipennis Hr. ? Kkps.
G. nordenskioldi Hr. Kkps.
Czekanowskia dichotoma Hr. Kks.
Cyparissidium gracile Hr. ? Kkps.
Sequoia reichenbachii Gein. Kkps.
Pinus peterseni Hr. Kkps.
P. crameri Hr. Kkps.
P. eirikiana Hr. Kks.
Carpolithes komensis Hr. Kk.
Cycad fruits.
Fasciculites grönlandicus Hr. ? Ks.
Laurus ? sp.

Although our collections appear to be from the same or equally low beds as those which yielded the rich Kook flora described by Heer, no cycads were here discovered by us. It is the cycads which give the Kome flora, as a whole, its interesting and antique facies. Diligent search was made in vain for the *Populus primæva* Heer, long recognized as the oldest and the only known Lower Cretaceous (Urgonian of Heer) dicotyledon. On the other hand, we found in these same beds and within 75 feet of tide several specimens of dicotyledonous leaves, which, though poorly preserved, appear to be comparable to *Laurus*.

The flora at the type locality of the Kome series does not, therefore, seem to be so unique nor indicative of a stage necessarily so low in the Cretaceous as has been supposed by many paleontologists. No determin-

* The symbols indicate as follows:
"K," previously reported in the Kome series.
"k," listed in Flora Fossilis Arctica as occurring at Kook.
"p," listed in Flora Fossilis Arctica as occurring at Pagtorfik.
"s," listed in Flora Fossilis Arctica as occurring at Ujarartorsuak.
"A," reported from Atane series.
"P," reported from Patoot series.

able fossil plants were found more than 100 feet stratigraphically above the lowest bed seen at tide level.

Nordenskiold, who published * the best geological section at Kook, was disposed to regard as Atane, or Upper Cretaceous, the beds at and above 750 feet above tide. At this level he obtained some fragments of *Sequoia fastigiata*, an Atane species, which led Heer † to admit the possible Upper Cretaceous age for the beds, though they were not so regarded by him. However, the absence of dicotyledons or other distinctively Atane species has hitherto left doubt as to the presence of the Atane series in this portion of the peninsula, and consequently as to the thickness of the Kome series. The collection made in 1897 at Ujarartorsuak fully establishes the existence of an extensive development of the Upper Cretaceous in the region of the typical Kome series. It is, accordingly, probable that not over 700 feet of Kome series is exposed at the type locality, and it is doubtful whether a greater development than 1,000 feet is anywhere visible.

The horizontally bedded Tertiary basalt, overlying the sedimentary series at an elevation of about 1,500 feet, extends to 6,330 feet above tide at the head of the Sarfafik glacier, in the Kilertinguak peak, a few miles west of Kook. The basalts are therefore probably more than 4,500 feet thick in this region.

Pagtorfik.—Between Kook and Pagtorfik (Pattorfik), the next westward of the richly phytiferous localities of the Kome series, the continuity of the nearly horizontal sedimentary beds is interrupted by several low hillocks or ridges of the old crystalline rocks and by great accumulations of basalt talus. The stratigraphy of Pagtorfik, from which the first large collection of plants was obtained by Nordenskiold in 1870, and a second by Dr Nauckhoff ‡ in 1871, has been briefly described by the former § and by Steenstrup.|| The coast profile is more gentle here than in most parts of this region, on account of the Pleistocene terraces, which from here to Avkrusat are especially well marked (see photograph of terrace near Ujarartorsuak, plate 25, figure 1). Up to 100 feet above tide the slopes are largely covered with glacial and other detritus, and of light colored or greenish-gray basaltic sands, often hardened into a tuff-like mass. From these terrace deposits several collections of fossil invertebrates have been made.¶

* Geol. Mag., ix, 1872, pp. 450, 452.

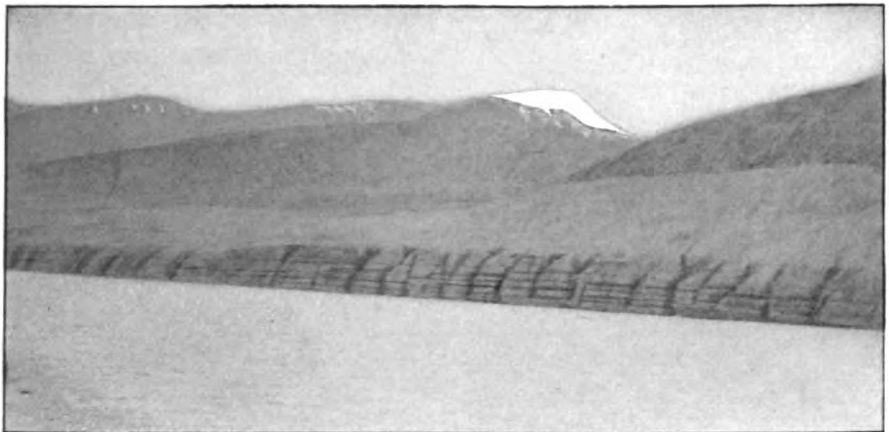
† Fl. Foss. Arct., vii, p. 54.

‡ Fl. Foss. Arct., vi, 1st Abth., Hft. 2, 1880, pp. 1-17, pl. 1-11.

§ Geol. Mag., ix, 1872, p. 450.

|| Meddel. om Grönland, v, 1893, p. 56. Op. cit., iv, 1893, p. 235. Heer: Fl. Foss. Arct., vii, p. 235.

¶ Nordenskiold: Geol. Mag., ix, 1872, p. 411. Steenstrup: Meddel. om Grönland, iv, 1893, pp. 235, 236. See profile sketch, p. 233, fig. 27.



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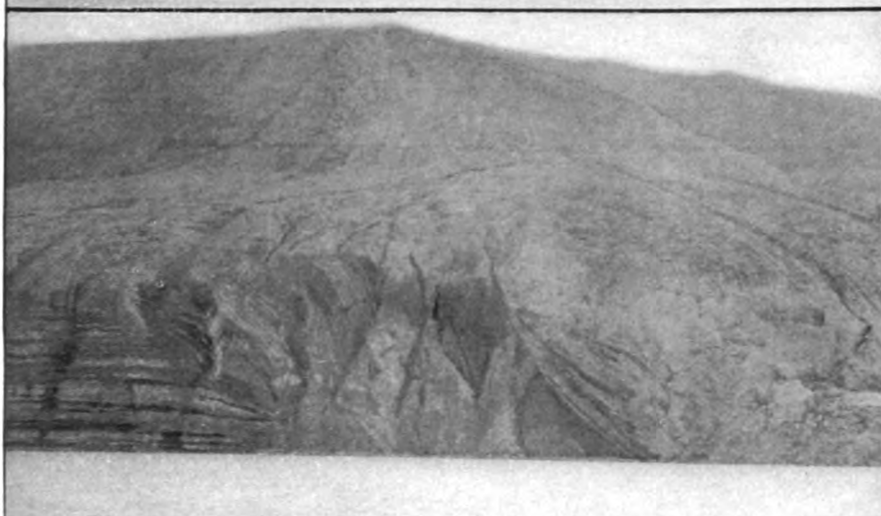

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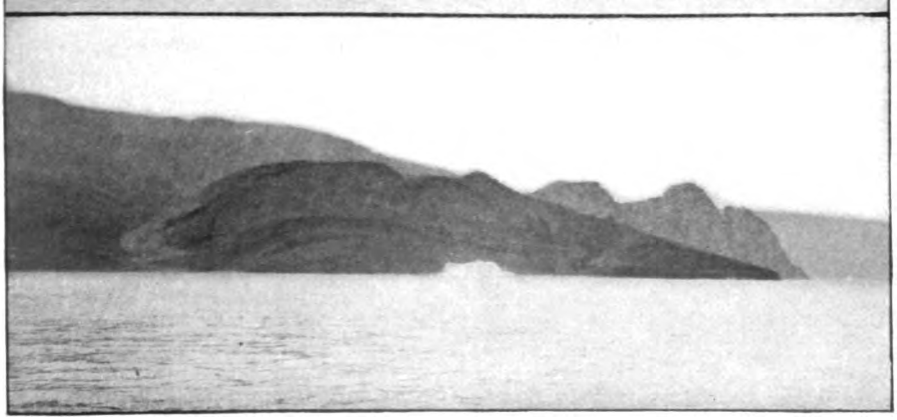

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FIGURE 1.—Postpleistocene terrace east of Ujarartorsuak, on cliffs of lightly eastward dipping Lower Cretaceous (Kome series).

FIGURE 2.—Ujarartorsuak; dislocation in Cretaceous; Kome series at the left.

FIGURE 3.—Niakornat; frontal promontory of basalt breccia, flanked by Upper Cretaceous and Tertiary basalts.

The specimens collected by the writers in this elevated beach were submitted to Dr W. H. Dall and Mr Charles T. Simpson, who report the following species, nearly all of which are still living in Arctic seas:

Pleistocene fossils in elevated beach at Pagtorfik.	Nordenskiold.	White and Schuchert.
Mya truncata L.	×	×
M. arenaria L.	×	....
Cyrtodaria siliqua Spgl.	×	×
Saxicava arctica L.	×	....
S. norvegica Spgl.	×	....
Tellina sabulosa Spgl.	×	....
T. tenua Leach.	×	....
Astarte corrugata Br.	×	....
A. semisulcata Leach	....	×
A. arctica Gray?	....	×
A. elliptica Br.	×	×
A. sulcata Costa	....	×
Cardium islandicum Chem	×	×
C. grönlandicum Chem	×	×
Leda pernula M.	×	....
Macoma sabulosa Spengler	....	×
Mytilus edulis L.	×	....
Mesodesma deaurata Turton	....	×
Pecten islandicus L	×	×
Buccinum hydrophanum Hancock	×	....

The plant-bearing beds at Pagtorfik consist largely of thin sandy and coaly shales similar to those at Kook, and lie unconformably upon the unevenly eroded gneiss in low cliffs along the shore. In these cliffs, the original source of Heer's *Populus primæva*, the strata have a slight easterly dip of less than 6°; but Steenstrup, who explored the ravines along the Pagtorfik stream, found a light coastward (north) dip at 245 feet above tide, and at an altitude of 392 feet he observed a dip of 30° to the northeast.

The following incomplete list of the plants collected by the writers at Pagtorfik seems to be characteristic of the Kome series:*

Taonurus sp.
Pteris frigida Hr. Kk.
Gleichenia gieseckiana Hr. Kkps.
G. zippei (Corda) Hr. Kkps.
G. comptoniæfolia (Ett.) Hr. Ks.
G. nordenskioldi Hr. Kkps.
G. gracilis Hr.? Kkps.
Nathorstia angustifolia Hr. Kp.
Nilssonia johnstrupi Hr. A.
Zamites speciosus Hr. Kks.
Z. arcticus Goepp.? Kks.
Inolepsis imbricata Hr. Kkps.
Frenelopsis hoheneggeri Ett. Kps.
Cyparissidium gracile Hr. Kkps.
Sequoia ambigua Hr. Kkps.
Sequoia gracilis Hr.? Kkps.
S. schmittiana Hr. Kps.
Pinus crameri Hr. Kkps.

*Unfortunately the reduced time allowed for the work in Greenland made it impracticable to make so large collections at many of the localities as was desired and at first intended.

Kaersut.—A little east of Pagtorfik the old crystalline rocks rise above tide (see plate 26, figure 1), and continue three or four miles to the west of Kaersut (Karsok), where a considerable mass of this rock is laid bare. Back of Kaersut it may be followed along the gorge to an elevation of over 360 feet, where it is concealed by extensive glacial boulder deposits.*

The Cretaceous series is exposed in the bed of the shifting stream at 580 feet above tide, but no determinable plants were found until we passed over the thin-bedded gray, sandy shales, thin sandstones, bluish or dark sandy shales, with coaly streaks to 700 feet above tide. Here well preserved plants occur in thin-bedded, black, slightly argillaceous shales. Slight dips to the northward and northeastward are here noticeable.

No dicotyledonous plants were found at Kaersut, which appears to furnish a typical Kome flora. The following is a partial list of the plants secured here:

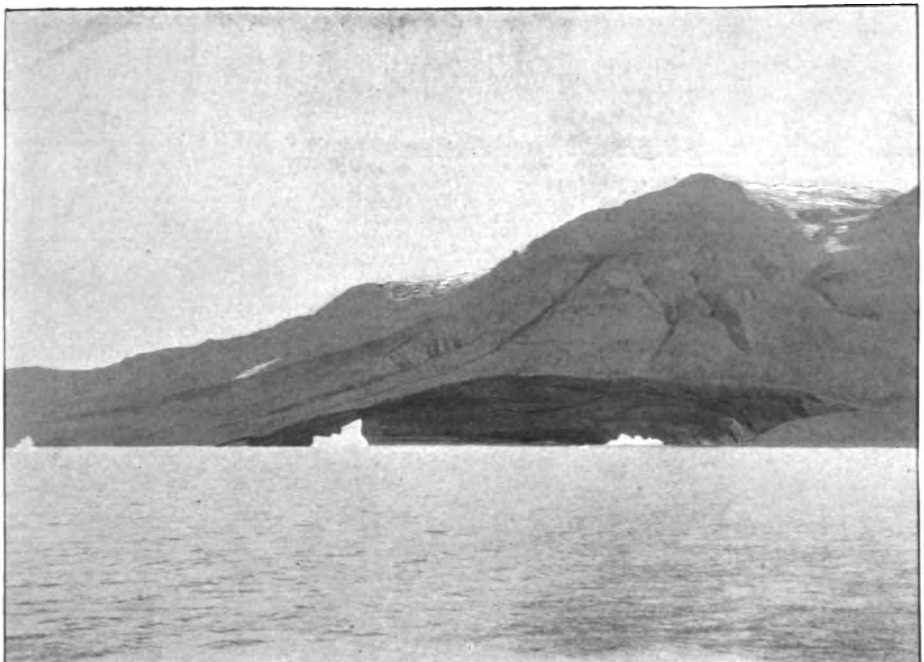
Thyrsopteris n. sp. ?
Asplenium dicksonianum Hr. Ks.
Pecopteris borealis Brongn. Kks.
Gleichenia rigida Hr. Kks.
G. zippei (Corda) Hr. Kkps.
G. longipennis Hr. ? Kkps.
G. gracilis Hr. Kkps.
Equisetum amissum Hr. Kkps.
Cyparissidium gracile Hr. Kkps.
Sequoia reichenbachii Gein. Kkps.
S. ambigua Hr. Kkps.
S. gracilis Hr. Kkps.
Dammara sp. ?

Above the plant bed, at 750 feet above tide, the Cretaceous series consists of dark sandy shales with coaly streaks, greenish conglomeratic sandstones, thin coals, thin gray soft sandstones, and dark sandy shales, sometimes filled with coaly smut. At an altitude of about 880 feet the shales have the appearance of being baked, particularly a coaly seam, which is coked and cemented to the slightly argillaceous sand. This horizon is a few feet beneath the base of a perpendicular cliff, more than 200 feet high, of heavy, horizontally bedded peridotite. In the sedimentary rocks above this extensive intercalated basalt series, at 1,346 feet above tide, Steenstrup † rediscovered the one-foot layer of graphite first described by Rink. Above this series the Tertiary basalts rise in steeply sloping knobs to the height of 6,250 feet above tide in the Kilertinguak peak. The occurrence at Kaersut of native nickel-iron in the basalt is also worthy of mention.

Ujarartorsuak.—Soon after leaving the hill of old crystallines and the glacial stream to the west of Kaersut, the Cretaceous is again seen along the shore in cliffs of about 100 feet in height. The series here con-

* This region has been briefly described by Nordenskiold in Geol. Mag., vol. ix, 1872, pp. 427–449, and Steenstrup, Meddel. om Grönl., v, 1893, pp. 56, 57; Heer, Fl. Foss. Arct., vii, 1883, pp. 235, 236.

† Op. cit., p. 236.



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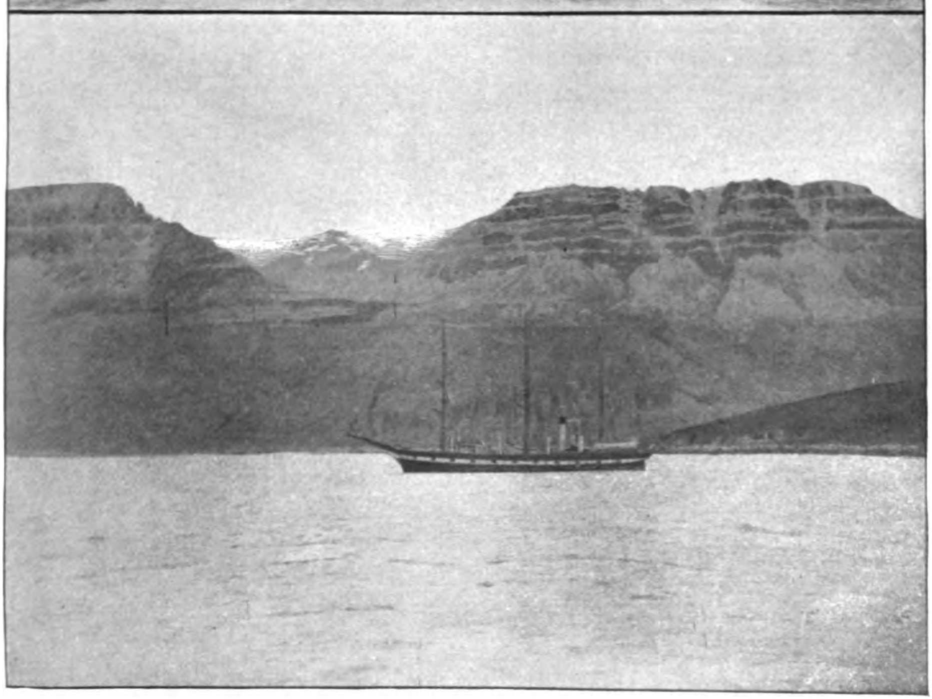

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FIGURE 1.—Kaersut, north coast of Nugsuak peninsula; hillock of ancient crystalline floor in foreground, surmounted by Lower Cretaceous, etcetera.

FIGURE 2.—Godhavn, Disco island; low ridge of old crystalline in lower right, flanked by Tertiary sediments and horizontally bedded basalts, weathering in benches.

Photographs published by courtesy of C. Lansing Baldwin, New York.

sists of thin, creamy or grayish, loose sandstones, or thin sandy shales, interbedded with numerous but variable carbonaceous strata, as at other localities. For a long distance above the shore cliff the ascent is quite gradual. This, the Pleistocene terrace, was also observed at Pagtorfik, and is shown in our plate 25, figure 1.

The Cretaceous beds are seen in the cliffs along the fiord dipping slightly but variably eastward, and it is highly probable that there is also a strong coastward dip as at the localities to the eastward. On approaching Ujarartorsuak (Slibesteensfjeld, Slibestensfield), the Avkrusat and Angiarsuit of Nordenskiold,* low hummocks of a bluish green highly altered basalt rise above tide level, and against these the Cretaceous rocks apparently rest unconformably.

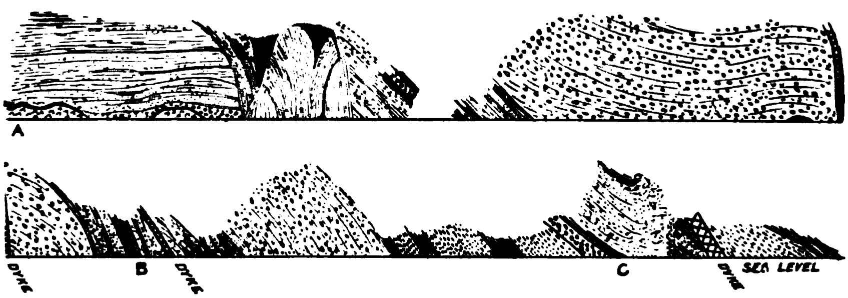

FIGURE 1.—*Rough profile sketch of cliffs below terrace at Ujarartorsuak (Slibesteensfjeld).*

A, B, C, plant beds.

A little west of the highly altered basalt the nearly horizontal Cretaceous series is suddenly interrupted. At this point throughout the complete height of the sea cliff the beds are crushed, broken, and dislocated for several hundred feet by a fault. Beyond this fault, which is dimly shown in the photograph, plate 25, figure 2, the strata consist of coaly shales, heavy sandstones, and sandy shales cut by three dikes. The composition of the series and the relations of the beds are best shown in the photograph, plate 25, figure 2, and the accompanying profile sketch, figure 1, which, though necessarily hastily made, conveys an idea of the stratigraphic sequence. It extends from about 75 yards east of the fault to the ravine near the abandoned houseplace, a distance of about 300 yards. It will be seen that the two westerly dikes are partially parallel with the bedding, which is not greatly disturbed, though the the local dips are plainly affected by the diagonally directed veins. In the face of the cliff near the fault the beds dip west about 45°. West of

* Geol. Mag., vol. ix, 1872, p. 450.

the main sandstone the dip is from 25° to 30°, while at the western end of the section the apparent inclination is about 10° to 15°. In the ravine at this point there is also shown a nearly equally strong seaward dip. The intrusive basalts in this region are believed to be of Tertiary age.

The important facts involved in this section are (1) the presence of a fault, and (2) the discovery of three floras, one east and two west of the fault.

In the nearly horizontal beds east of the fault ("A" of profile sketch) a flora clearly of Kome age, with an abundance of *Pinus crameri* Heer, is found. It includes the following species:

Adiantum formosum Hr.? Ks.
Asplenium boyeanum Hr. Ks.
Gleichenia zippei (Corda) Hr. Kkps.
Czekanowskia dichotoma Hr.? Kks.
Sequoia reichenbachii Gein. Kkps.
S. schmittiana Hr. Kps.
Pinus crameri Hr. Kkps.
P. peterseni Hr. Kkps.

The stratigraphic sequence along the shore to the westward of the fault is as follows:

Section at Ujarartorsuak from fault to west end of cliff

	Feet	
Dark thin interbedded sandstone and shales	25	
Thin sandstone	10	
Sandstone	10	
Concealed interval	50	
Thin coals with shaly partings	20	
Laminated sandy shales with coals	30	
Conglomerate with dike	100 ±	
Coaly shales	5	
Sandstone	8	
Coaly shales	2	
Sandstone	10	
		270
Sandy carbonaceous shale (plant bed "B")	15	
Sandstone	3	
Coaly shale	4	
Sandstone	20	
Basalt dike	2	
Coaly shale	2	
Sandstone	5	
Sandy shale	20	
Local disturbance here.		
Coaly shale	4	
Sandstone	6	
Coal	1.5	
Conglomerate	6	
Coaly shales and thin sandstone	12	

	Feet	
Conglomerate	80 +	
Coaly shale	8	
Sandstone	20	
Coaly shale	10	
Sandstone	25	
Thin sandstones and coals	10	
Coarse yellow sandstone and conglomerate	30	
Coaly shale	1	
Conglomerate	20	
		304.5 ±
		574.5 ±
Dark carbonaceous sandy shale (plant bed "C")	4.5	

The second plant horizon ("B" of profile sketch) is west of the fault and occurs about 30 feet above the heavy bedded conglomeratic sandstones. It has a clearly different flora from that found east of the fault in that dicotyledons are far more abundant than are the accompanying ferns, cycads, and conifers, although the number of dicotyledonous species is not great. The following named species occur here:*

Pteris frigida Hr. KkA.
Aspidium ursinum Hr. Kk.
Asplenium dicksonianum Hr. KsA.
Gleichenia rigida Hr. KksAP.
G. zippei (Corda) Hr. KkpsAP.
G. nordenskioldi Hr.? Kkps.
G. gracilis Hr.? KkpsA.
G. nauckhoffi Hr. A.
Nathorstia angustifolia Hr. Kp.
Cyparissidium gracile Hr. KkpsAP.
Sequoia reichenbachii Gein. KkpsA.
S. gracilis Hr. Kkps.
S. schmittiana Hr. Kps.
S. fastigiata Hr. AP.
Zamites speciosus Hr.? Kks.
Z. acutipennis Hr. Ks.
Pinus crameri Hr.? Kkps.
P. eirikiana Hr. Kks.
Phyllocladites rotundifolius Hr.? A.
Populus berggreni Hr. A.
Platanus heerii Lx. A.
Hedera primordialis Sap.? A.
Ficus atavina Hr. AP.
Cassia angusta Hr. A.
Laurus n. sp.?
Quercus n. sp. cf. *Q. rinkiana* Hr. A.
Quercus n. sp. cf. *Q. ferox* Hr. A.

The third locality ("C" of profile sketch) is some distance west or above the western conglomerate, being about 35 yards east of the third or western dike. Here again we find dicotyledons well represented along with ferns and gymnosperms of Upper Cretaceous age. This flora has:

Sphenopteris fragilis Hr.? Ks.
Dicksonia johnstrupi Hr. K.
Ginkgo multinervis Hr. A.
Widdringtonites reichii Hr. AP.
Sequoia fastigiata Hr.? AP.
Pinus eirikiana Hr. Kks.
Platanus heerii Lx. A.
Celastrophyllum cf. *newberryanum* Hollick.

*For the determination of the dicotyledonous remains the writers are indebted to the kindly assistance of Dr F. H. Knowlton, of the U. S. Geological Survey, who has also furnished the lists of plants collected at Ata and Patoot.

In association with these plants occur poorly preserved invertebrates. These were referred for study to Dr T. W. Stanton, who reports as follows:

"The few fossils from Ujarartorsuak are entirely different from any of the others [Atane, Patoot, or Niakornat] and probably are of more recent age. They appear to be all fresh-water forms and include one or possibly two species of *Unio*, an *Anodonta* (?), a *Sphærium*, and two species of gasteropods, each represented by a specimen too imperfect for generic determination. While these forms are such as might occur in the Upper Cretaceous, I think it more probable that they are from Tertiary beds."

Paleobotanists will see from the plant lists just given that the middle locality ("B" of section) exhibits a new and later phase than the typical Kome flora, while its relation to the Atane flora is so close, notwithstanding its transitional facies, as to strongly argue for a reference to the latter at the outset. The western flora ("C" of section) is plainly not older than the Atane. In fact the floras at Ujarartorsuak prove beyond doubt the hitherto questioned presence of the Atane beds in the midst of the Kome region on the north side of Nugsuak peninsula.

On ascending the rather steep little ravine at the western end of the section the coastward dip is found to vary from 15° to 35°. The same beds occurring near its mouth are also present at 500 feet above tide. Crossing over the narrow divide (700 feet above tide) to the west of the head of this ravine, one descends to the bed of the east branch of the glacial stream which debouches a short distance west of Ujarartorsuak. This branch flows from its bifurcation at 760 feet above tide to its mouth, just below the main glacier, at 360 feet above tide, on nearly the same stratum of ferruginous sandstone, just above which *P. crameri* is abundant in smutty shales. The series here is composed of thin streaks or groups of dark carbonaceous shale, or coals, intercalated in thin friable gray sandy shales. Sandstones, rarely 50 feet thick, occur up to an altitude of about 2,525 feet,* when the Tertiary basalt, many hundred feet in thickness, is encountered. From about 1,000 feet above tide the section is exposed in cliffs. There is, therefore, at least 1,400 feet of sedimentary rocks exposed beneath the basalt at Ujarartorsuak.

A little above the fork of this branch, at about 1,000 feet above tide another plant horizon was discovered which has the following species:

Sphenopteris lepida Hr. ? Kk.
Oleandra arctica Hr. Kkps.
Nathorstia firma Hr. K.
Ginkgo primordialis Hr. A.
Cyparissidium gracile Hr. KkpsAP.
Sequoia rigida Hr. KpsAP.
Phyllocladus rotundifolius Hr.
Sassafras arctica Hr. ? A.
Carpolithes thulensis Hr. K.

*Sandstones are more numerous in the intervals 1,000–1,200 feet and 1,900–2,340 feet, while coaly groups occur at 1,750–1,875 feet and 2,340–2,510 feet above tide.

This flora appears not to indicate a higher stage than that of locality "B," nor can it be later than locality "C" of the section. Stratigraphically, it is probably several hundred feet lower than "C." Assuming that it belongs in the Atane series, we are still in ignorance as to the thickness of the interval between it and the nearly horizontal Kome beds to the east, since a fault intervenes; but if we assume that the shales with *Pinus crameri* in the bed of the glacial stream are at the top of the Kome series, the horizon of this flora will be about 200 feet above the base of the Atane series. It is possible that it and the flora from locality "B" are ónly a few hundred feet higher than the Kome beds on the shore; or, in other words, that the dislocation at the fault is not great. The presence of the fault implies structural forces that may readily account for the slight generally prevailing easterly dips in the Kome series east of Ujarartorsuak and the rapid disappearance of these beds to the westward.

In coasting westward from Ujarartorsuak, or the Slibestensfield region, the basalt cap appears to descend, slightly truncating the cream or light colored sedimentary beds below. This apparent unconformity of the Tertiary basalt demands further observation and evidence. Steenstrup, who published a photograph and profile* of the coast at Ekorgfat (Ekkorfat, Ivnarsunguak), states that the sedimentaries rise to 2,650 feet, although Nordenskiold † gives the thickness as but 1,220 feet. It is possible that this is another of the not rare instances of difference of statement due to confusion of geographical names and uncertainty as to the precise points to which the names apply.

At Ekorgfat, as at Kaersut, an extensive mass of the old crystallines, 630 feet in height, is laid bare. Against this series abuts the Cretaceous, from which Nordenskiold collected plants at an elevation of about 600 feet above tide, while Steenstrup found amber and plant material near sea level. Thirty-three species were reported by Heer ‡ in the collections from Ekorgfat. No dicotyledons occur here, and no doubt has arisen as to the Kome age of the beds at this the supposed most westerly exposure of that series, although it is some distance west of the Upper Cretaceous exposed at Ujarartorsuak.

The basalt at Ekorgfat is said to rise to an altitude of 5,750 feet above tide.

Saviarkat.—West of Ekorgfat the slopes are largely concealed by loose material, perhaps Pleistocene in age.§ In the ravines are seen limited exposures of dark shales, which appear at varying elevations and in-

* Heer: Fl. Foss. Arct., vii, frontispiece, and p. 237, text-fig. Meddel., v, pp. 58, 59, text-fig.
† Geol. Mag., vol. ix, 1872, p. 450.
‡ Fl. Foss. Arct., vii, p. 153.
§ See Steenstrup in Heer: Fl. Foss. Arct., vii, p. 238, text fig.

crease in thickness in passing westward. These dark beds, composed of dark carbonaceous, hardly laminated, but rather sandy, shales, which soon comprise the greater part of the sections below the basalt, appear, both in their composition and fossil contents, to represent a more distinctly marine phase of the Upper Cretaceous.

At Saviarkat the dark series appears to extend, with occasional lighter zones, from the top of a knob of older (probably Mesozoic) basalt, rising about 300 feet above tide, up to the Tertiary basalt cap. In the upper part of the sections small irregular areas of pinkish-red shale, whose color and hardness is possibly due to oxidation, though the shale has all the appearance of having been burned, are seen in the walls of the ravines.

The dark series is the source of the calcareous ironstone concretions which furnished some of the invertebrate material very imperfectly described by de Loriol.* On exposed surfaces the shales slack rapidly into dark sandy material without evidence of bedding except occasional light bands. The result of this rapid decay is an unusually long slope in the spurs and deep cutting of the soft beds into steep ravines. These terminate in deep and abrupt gulches, each a "Kook Angnertunek."

On ascending the second ravine west of the pre-Cretaceous or older Cretaceous basalt cliffs at Saviarkat, the sides of the valley for some distance were found to be so thoroughly decayed as to obliterate the bedding. The irregularly rounded fossiliferous nodules occur in the stream bed and in the shales. At an altitude of 450 feet the strata are more freshly cut and reveal the bedding. The dip is nearly parallel with the gradient of the stream, and from 525 feet to over 700 feet above tide a thin slightly ferruginous layer, one of the nodule-bearing strata, is within reach of the hammer from the stream level, while at about 850 feet above tide this particular horizon passes under. The average dip in this ravine is over 900 feet to the mile toward the coast. It is only in the heads of the ravines that sections of the beds can be made.

The concretions are nowhere abundant and vary in size up to lenticular masses six feet long and two feet thick. A small percentage of these have marine fossils and fragments of wood. Dr T. W. Stanton, to whom these fossils were submitted for study, reports the following:

"The localities between Saviarkat and Kook Angnertunek and Niakornat are evidently on essentially the same horizon, and the species collected include a number of characteristic Upper Cretaceous types that allow us to refer the beds without question to the Senonian of Europe, corresponding with the Montana formation (Fort Pierre and Fox hills) of the western United States. A number of the forms are closely similar to Fort Pierre species, though I have not been able to confirm

* Meddel., v, pp. 203–213. Heer: Fl. Foss. Arct., vii, pp. 250–256.

actual specific identities which de Loriol * recognized in several cases when studying collections from these beds.

"The fossils from between Saviarkat and Kook Angnertunek include:

Scaphites, two species.
Actæon sp. Aff. *A. attenuatus* M. and H.
Bulla or *Haminea*, two species.
Xenophora ? sp.
Anchura sp. Aff. *A. americana* (E. and S.)
Lunatia sp. Aff. *L. concinna* H. and M.
Dentalium sp.
Teredo.
Crenella.
Lucina, three species.
Mytilus.
Pecten ataensis de Loriol.
Nucula, two species.
Several undetermined small bivalves and gastropods, with shark's teeth and fish scales and vertebræ."

On account of the relations of the Saviarkat-Kook Angnertunek fauna to that found in the Atane series on the south side of Nugsuak peninsula, the dark beds toward the western en d of Nugsuak peninsula have been provisionally correlated by the Danish geologists with the Atane series.† Fragments of ferns also were collected in these nodules, but they have not yet been studied.

Kook Angnertunek.—Three or four miles west of Saviarkat, at the ravine to which the name Kook Angnertunek is specially applied, the dark series is well exposed, retaining the coastward dips. This locality has been briefly described by Steenstrup.‡ The entire thickness of the sediments here may not exceed 1,200 feet, although in the clear atmosphere, without standards for comparison, it is difficult to form estimates that are even approximately correct. The nodules, which are exceedingly tough and elastic, are here more frequently fossiliferous, although not more than five per cent contain specimens of value. A fragment of silicified wood was found in the bed of the stream.

Niakornat.—Beyond Kook Angnertunek the sedimentary series appears, as viewed from the sea, to be at first nearly horizontal, followed by an easterly dip, demonstrated by the westerly elevation of a brownish ferruginous band. It is possible that this may be merely the apparent dip due to the cessation of the strong coastward inclination seen farther east.

At Niakornat a promontory of two knobs of early Cretaceous or pre-Cretaceous breccia basalt (plate 25, figure 3), connected at tide level by a slender isthmus of sand, forms a curious and highly scenic feature.§ As at Saviarkat, the landward knob, which is said to attain a height of 960 feet above tide, is flanked by the dark shale series so well developed

* Ueber die marinen Thierversteinerungen von Nord-Grönland. Heer's Flora Fossilis Arctica, Bd. vii, pp. 251-256, Zürich, 1883.

† See Kaart over Grönland, af R. Hammer og K. I. V. Steenstrup. Meddel., iv, 1893.

‡ Meddel., v, pp. 59, 60. Fl. Foss. Arct., vii, p. 238. See Heer, op. cit., p. 165.

§ See also photograph of Niakornat by Steenstrup; Meddelelser, iv, pl. vii, fig. 1, p. 289.

at Kook Angnertunek. The invertebrate fossils found here are identical with those of the locality just mentioned and belong to the Montana formation, or the Senonian of Europe. The Tertiary basalt descends here to 1,480 feet above tide, and a few feet beneath it Steenstrup observed a previously described stratum of graphite, occurring under conditions similar to those attending the upper graphite at Kaersut.

Beyond Niakornat the sedimentary series dips rapidly and disappears west of Iterdlak. Then for a long distance the basalt forms the sea front, in precipitous cliffs streaked with red ferruginous bands. Throughout the western coast of Nugsuak peninsula the Tertiary basalt appears to have a general westerly dip. Basalts tower up along the shore, or in cliffs some distance back of the beach, all the way around the outer portion of the peninsula to near the native village Nugsuak, at its extremity. On the south coast, east of Niakornarsuk, it occurs in high precipices over which the smaller streams fall in cascades for hundreds of feet. Nevertheless sandstones and coal-bearing shales of Tertiary ("Miocene") age are reported from the valley back of Iterdlak, the vanishing point of the Cretaceous on the north shore, and near Nugsuak. At Ifsorisok, a place in the interior nearly midway between the two last named localities, Nordenskiold also obtained Tertiary fossil plants. At Natdluarsuk to the southeast of Nugsuak, Nordenskiold and Steenstrup found Tertiary coals and sandstones between 1,300 and 1,700 feet above tide dipping 10° to the west, with both floor and cover of basalt. Again, some distance east of Niakornarsuk, within the western entrance to the Vaigat, the buff beds of the Tertiary are seen in the cliffs near the shore.

PRINCIPAL FOSSILIFEROUS LOCALITIES OF THE SOUTH SHORE OF NUGSUAK PENINSULA

The Cretaceous on the south side of Nugsuak peninsula first appears on the coast about a mile west of Alinaitsunguak. Here occur about 600 feet of buff, more or less coarse sandstones, dark coaly or smutty shales, and laminated thin sandy shales streaked with carbonaceous layers. A few dikes and intrusive beds of Tertiary basalt traverse the Cretaceous series, which is capped by a fortress-like mountain of basalt. The sedimentaries dip about 15° to the eastward and pass beneath tide level within a mile. Only fragments of plants were found by the writers at this point. The material collected here by former visitors was pronounced by Heer* to belong to the Atane series.

Ata (*Atane*).—Ata, the type locality of the Atane series, the middle of the three divisions of the Greenland Cretaceous † established by Heer, is situated about 18 miles east of Alinaitsunguak. Here the principal

* Fl. Foss. Arct., vii, p. 164.

† Correlated with the Cenomanian of Europe.

terranes are a body of brecciated pre Cretaceous basalt, extending to a considerable height to the left of the ancient houseplace, and a series of buff sandstones, with thin gray or creamy, more or less laminated and carbonaceous shales. In irregular areas the latter are reddened and hardened, as well as de-carbonized, being the "burnt shales" described by the Danish geologists. The sedimentaries attain an elevation of 2,180 feet above tide, where the vertical walls of Tertiary basalt continue over 1,000 feet higher.

The general lithological characters appear to differ little from those of the Kome or Atane series on the north side of the peninsula, the only observed difference being the frequent local occurrence of the red shales, whose peculiar character is secondary, and a slight increase in the number of sandstones.

About a mile and one-half west of the houseplace a knob of "red-burned shales" rises from tide level west of the brecciated basalt, and is flanked by basaltic and other talus. Here, in the thin, fissile, brittle, and ringing shales, numerous casts of marine invertebrates and, rarely, fragments of plants are found. Nearer the houseplace, at an elevation of about 250 feet above tide appear buff or slightly yellowish thin sandstones and laminated shales with poor dicotyledonous leaves and occasional shells. At the same horizon farther east the sediments are altered to a brick red. Above this the slope of the coast is mostly concealed by basalt talus to an elevation of 1,400 feet, when coaly or smutty sandy shales, thin buff sandstones, and conglomeratic strata, rarely containing plant and invertebrate remains, continue to an altitude of 2,000 feet above tide. Above the latter are about 180 feet of arenaceous beds capped by the Tertiary basalt. The latter dips slightly to the west. It may be noted in this connection that the character of the sediments below the basalt cap varies considerably. In places heavy cream colored sandstones, or thin shaly sandstones, or carbonaceous shales, often appearing to have been burned red, underlie the basalt, while at Patoot and Atanikerdluk one or more masses of considerable thickness of basalt are interbedded. Some distance east of the houseplace at Ata the shales descending to tide level are "burned," and sparingly contain leaves and invertebrates. Still further east, at Kugsinersuak, the thin sandstones and shales are not altered at the mouth of the river gorge, although the same beds along the sea front, perhaps less than 100 yards distant, are thoroughly reddened or leached, the shales brittle and ringing.*

*Steenstrup (Meddelelser, v, 1893, pp. 63, 64; Heer, Fl. Foss. Arct., vii, pp. 164, 165, 240, 241) is perhaps correct in regarding the red ringing brittle shales in the vicinity of Patoot as mainly due to baking, since in rare cases these red areas are near dikes or outflows of Tertiary basalt. However, in several areas where red shales are found there are no visible dikes, and the shales have possibly attained their red color by oxidation.

At this point, from 50 to 100 feet above tide, are exposed thin sandstones, above which occur about 75 feet of the dark shale. This shale, which was reddened a little farther west, is here unaltered and reveals numerous impressions of leaves, some of which are well preserved. Large fragments of fossil tree trunks are occasionally met in debris in the bed of the stream and on the broad glacial fan.

Regarding the invertebrates found at Ata, Dr Stanton reports the following:

"The collections from the vicinity of Ata are apparently all of about the same age and they are doubtless from the same beds that furnished the collections studied by de Loriol. Unfortunately, there are no ammonites nor other strictly characteristic Mesozoic forms in the collections, and our comparisons must be limited to a few species that are also found in the Cretaceous beds on the north side of the peninsula; these are *Pecten ataensis* de Loriol and two species of *Lucina*. Although these are forms that might occur in the Tertiary as well as the Cretaceous—that is, they are persistent types still represented by similar forms—their *specific* identity with fossils found in the same general region with characteristic Cretaceous species makes it probable, in the absence of contradictory evidence, that the beds in which they occur are of about the same age as the Upper Cretaceous beds on the north side of the peninsula.

"The fossils from one mile east of the houseplace at Ata are a small *Nodosaria*, *Pecten ataensis* de Loriol, *Leda* (?) sp., two species of *Lucina*, and a fragment probably of *Solemya*, with undetermined casts and impressions of small bivalves that may represent other genera.

"The locality one and one-half miles west of Ata yielded a larger collection of the same species, with additional forms as follows:

Echinoids, indeterminate fragments and impressions.
Pecten ataensis de Loriol.
Arca sp.
Leda, two species.
Lucina, four species.
Ostrea ?
Modiola ?
Cuspidaria sp.
Dentalium, two species.
Crustacea, indeterminate fragments and impressions."

At this locality were found the following plants, kindly identified for us by Dr F. H. Knowlton:

Juglans arctica Hr. (small leaflet). A.
Sequoia rigida Hr. ? KAP.
Andromeda pfaffiana Hr. ? A.
Laurus plutonia Hr. ? AP.
Laurus angusta Hr. AP. And other fairly good leaves not identified.

Dr Stanton reports that—

"The collection from west of houseplace at elevation of 175 feet yielded only a smooth species of *Avicula* having about the form of *A. nebrascana* E. and S., but lacking the radial sculpture.

"From locality 1,800 feet above sea level, at Ata, the only recognizable fossil is a *Lucina* identical with a species occurring at one and one-half miles west of Ata."

Patoot.—In that portion of the coast known as Patoot the profile of the escarpment is very strongly concave, beginning in the upper part by lofty cliffs of horizontally bedded Tertiary basalts and tuffs about 3,000 feet in thickness and ending in a long gentle talus slope to sea-level. The contour of the igneous cap is but slightly affected by the abruptly heading, steeply V-shaped ravines (whence the name Patoot) in the clastic series below. This region is exceptionally favorable for the observation and study of the "burned shale" mentioned under the preceding locality. As noted by Steenstrup,* these shales are here occasionally a creamy white, as though leached. Frequently the red areas occur near the lower talus slope, but they rarely attain the Tertiary basalt above. Dikes occur here and there, but it is not often that the red shales are in proximity to either a dike or outflow.

The sedimentary series at Patoot does not appear to differ, save by the greater number of "burnt" masses, from that described at other places; nor is there any notable lithological or stratigraphical difference in the composition of that portion of the series exposed below 500 feet above tide (Atane series as differentiated paleobotanically by Heer) and the succeeding beds (Patoot series of Heer), except near the top beneath the Tertiary basalt, where, at 2,600 feet above tide, there is frequently a sandstone series about 300 feet in thickness. This sandstone may, however, be of Tertiary age.

The plant and invertebrate bearing beds below 470 feet above tide were included by Heer in the Atane series.† Since the fossils found above 500 feet above tide were regarded by him as indicative of a later age in the Cretaceous than the Atane (Cenomanian), he established for them a new series, the Patoot series, of which the rocks here exposed constitute the type section. The flora, embracing 116 species, is correlated with the Senonian of Europe. Elevation above tide is not, however, a reliable criterion for distinguishing the two series. In one of the easterly ravines the strata are exposed unusually low (350 feet above tide) and dip about 15° to the south. The stream flows over the oblique edges of the strata, so that at 750 feet above tide the rocks are 100 to 200 feet lower stratigraphically than at the mouth of the ravine. A few fragments of plants were collected in these low beds, the most abundant leaves identified by Dr Knowlton being *Platanus heerii*, a species which occurs at Ujarartorsuak, on the north coast, and which is reported by Heer as found only in the Atane series.

In another ravine, farther west, the coastward dip is perhaps equally strong. On ascending a steep spur at this point we found fragments of

* Meddelelser, v, 1893, p. 65. Heer: Fl. Foss. Arct., vii, pp. 164, 169, 242, 243.
† Fl. Foss. Arct., vii, p. 164.

a *Platanus*, which seems to be *P. heerii*, in dark carbonaceous sandy shales at 1,370 feet above tide. At 1,640 feet above tide occasional ferruginous ironstone bands containing conifers, dicotyledons, and ferns occur, while an abundance of silicified wood and occasional erect stumps were found at and above this horizon. Owing to the dip, it seems probable that not more than 2,000 feet of clastic rocks are here exposed.

Poorly preserved invertebrates occur at a number of levels in the red areas to the east of Patoot. Regarding these, Dr Stanton reports as follows:

"The most common species from Patoot is an echinoid that is doubtless the same species that de Loriol identified with *Hemiaster humphreysianus* M. and H., which occurs in the Fort Pierre beds. With this crushed and imperfect material, however, the identification is necessarily very doubtful, as neither generic nor specific features are sufficiently preserved.

"With these echinoids there are an *Avicula*, probably undescribed, a *Pinna* (?), a *Dentalium*, and indeterminate fragments of a crustacean. The *Avicula* is of a type common in the Upper Cretaceous, but the fossils can hardly be considered sufficient in themselves to decide whether the beds are Upper Cretaceous or more recent."

On one of the eastern spurs, at an altitude of 720 feet above tide, good fossil plants are also found in association with invertebrates. These have been identified by Dr F. H. Knowlton and may be regarded as typical of the Patoot flora:

Arundo grönlandica Hr. AP.
Platanus newberryana Hr. P.
Platanus affinis Lx. ? AP.
Platanus sp. (Figured by Heer.)
Quercus cuspidigera Hr. P.
Quercus johnstrupi Hr. P.
Quercus myrtillus Hr. P.
Dewalquea insignis Hos. and Marck. AP.
Diospyros primæva Hr. AP.
Diospyros steenstrupi Hr. P.
Viburnum multinervis Hr. P.
Macclintockia cretacea Hr. AP.
Sapotacites hyperboreus Hr. P.
Rhamnus brevifolius Al. Br. Tert.
Gleichenia gieseckiana Hr. KAP.
Gleichenia nordenskioldi Hr. K.
Aspidium oerstedi Hr. AP.
Aspidium meyeri Hr. ? Tert.
Aspidium (in fruit).
Aspidium ? n. sp.
Sequoia concinna Hr. P.

Atanikerdluk.—East of Patoot the Cretaceous outcrops in the long talus slopes near Manik, and again between Kingitok and Kardlok. Good exposures are found near both the latter localities, that near Kardlok being near the shore and in contact with low irregular bluffs of pre-Cretaceous or very early Cretaceous basalt. One of these irregular masses of basalt forms, at Atanikerdluk, a double hooked peninsula between 300 and 400 feet in height, extending nearly a mile from the mainland.

The terranes in this vicinity have been more thoroughly studied, both geologically and paleontologically, than any other portion of North Greenland. The well preserved, but broken, Tertiary plant remains in the ironstones of the higher strata were early known to the Danish trade administrators and explorers of other nations, and among the contributors of material derived from this locality and elaborated in Heer's Flora Fossilis Arctica are found the names of Rink, Olrik, McClintock, Inglefield, Colomb, and Whymper. Brief geological descriptions were published by the earlier writers; but Robert Brown * was the first to give a satisfactory description of the varied features of this most interesting locality. Later, Nordenskiold † and Steenstrup ‡ made important additions to the flora and contributed valuable details and illustrations. For a detailed geological section the reader is referred to Brown's memoir,§ and for illustrations of the dikes to the papers by Nordenskiold and Steenstrup.

At Atanikerdluk the lowest Cretaceous rocks at tide level consist of small areas of rather strongly northward tilted thin sandstones and dark shales. At several points in the little peninsula they are unconformably covered by the massive coarse-grained doleritic basalt rising to a height of 320 feet.|| In the large ravine immediately to the east of Atanikerdluk the dip varies from 25° to 35° to the northeast.

From the lower shales in the peninsula at Atanikerdluk a flora, chiefly ferns, gymnosperms, and dicotyledons, was described by Heer and correlated with the Atane flora. Back of the little peninsula the Cretaceous occurs near tide level, and consists of thin sandstones alternating with dark, often coaly shales. Near the foot of the slope poor plant material was gathered.¶ Immediately opposite the western border of the isthmus connecting the little peninsula with the mainland, at about 200 feet above tide, occur thin dark shales filled with plant fragments. This, the "Liriodendron bed" of Heer, has yielded an abundant flora—in fact, the richest one of the Atane series. The shales are very soft and badly broken, the plants being far less complete and dis-

* In notes credited by Heer to Edward Whymper, op. cit., vol. ii, pp. 447, 449–451. Also: Geological notes on the Noursoak peninsula, Disco island, and the country in the vicinity of Disco bay, North Greenland, by Robert Brown. Trans. Geol. Soc. Glasgow, vol. v, 1875, pp. 55–112, geological map.

† Geol. Mag., vol. ix, 1872, pp. 452–457, figs. 10–13.

‡ Meddelelser om Grönland, v, 1893, pp. 67–69; sketch map, p. 67; ravine section, p. 68; profiles and sections with dikes, f. 8, 9; also in Heer, Fl. Foss. Arct., vii, pp. 243–245, sketch map, geological map, and panorama-frontispiece.

§ Reprinted in "Manual and Instructions for Arctic Exploration," 1875, pp. 467–481.

|| The writers are uncertain as to whether the Cretaceous rocks are here interstratified with the eruptive rock, or the latter is laccolitic in its nature. The whole mass seems to have been affected and perhaps slightly metamorphosed by the later Tertiary epirogenic movements to which the locally variable dips are probably due.

¶ This locality is farther eastward than that indicated in the panorama or sketch map given by Steenstrup.

tinct than would be inferred from the figures in the "Arctic Flora." Above the Liriodendron bed for several hundred feet few, if any, fossils have been found, and the termination of the Atane or Patoot series has therefore not yet been located. The dark shales and thin sandstones appear to continue upward in a uniform and regular series nearly to 1,000 feet above tide in strong lithological resemblance to the Upper Cretaceous with marine invertebrates seen at Saviarkat, Kook Angnertunek, and Niakornat.

On ascending the small ravine to the right of the Liriodendron bed,* at about 1,000 feet above tide, we find a somewhat heavy and slightly conglomeratic sandstone nearly 125 feet in thickness. Dark sandy and argillaceous shales, the same beds that, farther east, yield the richly phytiferous ironstones (Tertiary bed No. I of Steenstrup) then ensue to about 1,200 feet above tide; but in the western ravine the ferruginous masses are small and scarce, and no fossils were found in them. At 1,775 feet above tide the shales are interrupted by basalts which crown a sharp conical spur to the left of the head of the run. The tertiary shales and thin sandstones are, however, soon renewed and continue, with possible slight basalt interruption, to a height of 2,625 feet above tide, when other beds of basalt occur, continuing to 2,770 feet above tide. From this level another series of shales extends to the base of the main eruptive cap (3,040 feet above tide), no other sedimentaries being visible in this region.

The small conical knob, Tertiary bed No. IV of the illustration cited, is situated about one mile to the westward, and is composed of the upper portion of the Tertiary ("Miocene") shales and a small remnant of the basalt cap. The shales in the lower part of this knob are mostly thin, fissile, and black or dark gray. In the rather more arenaceous shales about 75 feet below the basalt are found the thin ferruginous layers from which a few poor plant fragments were obtained by Steenstrup and the writers. The aspect of these plants is more modern than that of the typical Atanikerdluk (Tertiary) flora.

Above the older basalt the light sands and coaly shales appear to become wedged in the cape to the west of the mouth of the deep river valley, though the Tertiary extends for a considerable distance up this valley. East of this river, which is but little more than eight miles from Atanikerdluk, the sedimentary series has disappeared, and the older crystallines rise to a height of 2,100 feet above tide. The contrast between the Tertiary and basalts on the west and the irregular topography of the

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* Locality no. 2 of sketch, Flora Foss. Arct., vii, p. 244, or frontispiece of same volume. Meddelelser om Grönland, v.

gneiss on the east is so sharp as to suggest another fault in the Nugsuak peninsula.

An interesting feature of the geology in the region of Atanikerdluk are the dikes. These are not rare along the eastern coast of Disko island and on either side of the Vaigat, and more particularly along the northwest coast of the outer portion of the Nugsuak peninsula. They appear at various angles and without regular trend, but the irregularity is especially marked about Atanikerdluk. At the latter point we have, as described by Brown and Nordenskiold, fine examples of crossed and forking dikes. The attitude of these, as illustrated by Steenstrup* and by Nordenskiold,† is apparently independent of the position of the sedimentary strata or the occurrence of rigid beds. A notable circumstance in this connection is the presence of the "burned shales" in the Tertiary from 1,275 feet to about 1,475 feet above tide on the west side of the large ravine.‡ The sandstones and shales in contact with the dikes in the ravine are, however, slightly altered for a very little distance, but are not reddened. There is no subaerial evidence of a dike or other eruptive material in contact with the area of reddened hardened shales.

For some distance eastward from the Atanikerdluk peninsula the strand is hemmed by cliffs of the Cretaceous,§ while exposures, probably of the older basalts, recur at tide level as a number of reefs off Tokternuk and in the ledges of Ivnarsuit.

Summary and Conclusions

(1) The Cretaceous and Tertiary rocks in the region described lie everywhere unconformably upon a hilly basement of old crystallines, chiefly gneiss and diorite (Kaersut, Pagtorfik, Ekorfat), or upon early Cretaceous or pre-Cretaceous (?) basalts (Niakornat, Alinaitsunguak, Atanikerdluk). The greatest altitude of the sedimentary terranes is at Atanikerdluk, 3,040 feet above sealevel. The old basalts are highly altered and usually occur as breccias (Niakornat, Alinaitsunguak).

(2) The prevailing easterly dips of the Lower Cretaceous along the north side of Nugsuak peninsula, in which the strata should dip westerly, since it is in that direction that the higher and younger beds appear, may be in part explained by fault compensation, as illustrated at Ujarartorsuak. A certain degree of irregularity of dip, the variable and often

* Meddelelser om Grönland, v, frontispiece. Fl. Foss. Arct., vii, frontispiece.

† Geol. Mag., vol. ix, 1872, p. 457.

‡ They include Tertiary plant bed no. ii of Steenstrup's sketches and Heer's descriptions.

§ In the large ravine immediately to the east of Atanikerdluk the dip varies from 25° to 35° to the northeast, although farther east the edges of the strata seem to indicate less inclination in the cliffs along the shore.

strong coastward dips, as well as the low altitude of the Tertiary at its eastern border on the south side of the peninsula (Atanikerdluk). are probably due to inequality in the post-Tertiary epeirogenic movements.

(3) The sediments appear to have been derived from the east, since the light-colored sandstones and conglomerates are most abundant on that side of the sedimentary belt (Kook, Kaersut), where marine fossils appear to be wanting. At one of the eastern localities (Ujarartorsuak) fresh-water shells occur with plants. To the west, dark homogeneous shales with abundant remains of marine animals predominate.

(4) Sedimentation appears to have been continuous in some portion of this region throughout Cretaceous and early Tertiary times, since no marked unconformities or unmistakable evidence of interruption of deposition have been seen. In certain sections, however, there appears to be, either in a variable thickness of the series or a slight difference of attitude, evidence of movements or erosion prior to the imposition of the Tertiary basalt cap, though these may be only local or of minor extent. But in many well exposed sections there is no local trace of sedimentary discontinuity between the Mesozoic and Tertiary.

(5) The entire thickness of the clastic deposits is probably over 3,500 feet. They are divided by Heer into four series, on the basis of their vegetable contents. Of the lowest of these, the Kome series, developed on the north coast of the peninsula, a thickness of probably not over 700 feet is exposed above tide. The discovery of additional dicotyledons in the Kome series, from which hitherto only *Populus primæva* was known, and which was regarded as Urgonian in age by Heer, casts serious doubt on the reference of those beds to so low a stage in the Lower Cretaceous. The flora as a whole is, however, to be compared with that of the Virginian Potomac formation, with some, perhaps the upper, portion of which the Kome series is probably synchronous.

The Atane series, hitherto not positively known on the north shore of Nugsuak peninsula, is clearly present at Ujarartorsuak with characteristic Atane plants. Farther west, at Kook Angnertunek and Niakornat, the dark homogeneous shale series probably represents both the Atane and Patoot members of the Upper Cretaceous, since of the marine organisms found here some are identical with those occurring at Ata and Patoot, the typical localities for the two divisions of the Upper Cretaceous. The marine invertebrates from the Atane series, which Heer correlated by means of fossil plants with the Cenomanian of Europe, strongly indicate that the series is to be correlated with the Fort Pierre and Fox Hills or Montana formation of the western United States. Paleobotanically the Atane series is so closely related to the Vineyard series of Marthas Vineyard, the Amboy clays of the Raritan region of

New Jersey, or the uppermost Potomac of Alabama as to furnish strong reason for the belief that the middle of Heer's groups is the Greenland contemporary of the Amboy clays. The Patoot series, which appears lithologically and stratigraphically to be inseparable from the Atane series, contains at the same time many plants common in the upper part of the Amboy clays, with others allied more closely to the higher Cretaceous floras, such as that of the Laramie. The Patoot series may perhaps be safely interpreted as constituting a paleontological as well as sedimentary transition from the Atane series to the Tertiary. The thickness of the Atane and Patoot series (Senonian) is not less than 1,300 feet and may considerably exceed this.

The Tertiary clastics at Atanikerdluk attain a thickness of not less than 1,500 feet, not including the intruded basalts at least 200 feet thick. The horizon of most of the plants described by Heer as Miocene is assumed to be near the base of that series, the demarkation of which appears to be purely arbitrary.* It is more probable that the age of the plants now generally conceded by paleobotanists to be Oligocene may even be Eocene instead of Miocene. No remains of marine animals have as yet been discovered with these plants.

The Tertiary clastic zone appears to be thinner west of Atanikerdluk, and at Patoot and Atane it is presumably represented by the upper sandstone horizon 200 to 300 feet in thickness. At the western end of the peninsula its presence is established in the occurrence of "Atanikerdluk" plants. On the north coast east of Niakornat there may be a slight development of this zone, and it evidently is represented in the interior east of Kook.

The systematic differentiation of the described plant material from the Greenland Cretaceous, by means of which so important a distinction between the floras of the three series, as well as such voluminous local floras, was attained, appears to have necessitated a refinement in species separation that seems in many cases to be impracticable if not impossible of satisfactory recognition.

(6) An apparent angle between the horizontally bedded Tertiary basalt and the supposed Upper Cretaceous sediments west of Niakornat may warrant the hypothesis of Tertiary erosion in that vicinity. On the south coast, at Atane and Patoot, the Tertiary sediments are thought to be thinner than at Atanikerdluk, which lends further support to this supposition.

* The conglomeratic sandstone at 1,000 feet above tide at Atanikerdluk, assumed by the writers to be the base of the Tertiary at that point, is the only hypothetical lithological bench mark observed in any section.

(7) The entire region of the west coast of Greenland in which Mesozoic or Tertiary sediments are now found is capped by a great number of superimposed, approximately horizontal, non-columnar basalt beds of varying thickness and of great extent. Frequently 3,000 feet of this basalt cap remains, while at Kilertinguak (6,250 feet above tide) over 4,000 feet is preserved.

In certain regions numerous dikes intersect at varying angles the Cretaceous, Tertiary, and even the lower portion of the basalt cap, and are frequently found both forking and intersecting. Intruded basalts are not rare, especially in the Tertiary. The peridotite intrusive beds, about 350 feet thick, back of Kaersut are probably of Tertiary age, as are also the other high intercalated basalts.

At the time of the great elevation of the region, probably in the late Tertiary, the basalt cap, which, judged by the development on Unbekanntes island, may have exceeded 7,000 feet in thickness, most probably extended in an unbroken sheet from the south of Disko island north to beyond the Svartenhuk peninsula, a distance of 250 miles.

(8) The dissection of this great basalt sheet, the development of the Vaigat, the Umanak fiordal system, the isolation of Disko—in fact, approximately the present land topography of this coast—were accomplished at a much greater elevation during Pleistocene time.

(9) Evidence of post-Pleistocene subsidence, with Arctic climatic conditions, is found in the presence of recent Arctic marine shells occurring in terraces at an elevation of from 100 to 150 feet above tide. In the old crystalline region much farther south the terracing is said to extend to 300 feet above tide.

(10) The extent of the more recent uplift is not known, since the retreat of glaciers, the inundation of ancient dwelling sites, and the records of tide gauges point to present downward movement observable within historical time.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 9, PP. 369-390 JUNE 22, 1898

ON THE OCCURRENCE OF MAMMOTH AND MASTODON REMAINS AROUND HUDSON BAY

BY ROBERT BELL

(*Read before the Society December 29, 1897*)

CONTENTS

Introduction

In the following paper on the discovery of the remains of both the mammoth and the mastodon around Hudson bay it is proposed to give a short account of the geological surroundings of each of these discoveries, and to refer very briefly to the consequent extension of our knowledge of the geographical range of both species over a vast area, and also to notice some of the questions which they suggest, such as those relating to the climates of the regions in which these animals flourished, the geological dates when they lived in the old and the new worlds, their general geographical distribution, migrations, causes of their extinction, and other matters of geological importance concerning them.

The Occurrence of a Mammoth Tooth on the east Coast of Hudson Bay

In 1877 I made a geological exploration of the east side of Hudson bay. In the following year a remarkable molar tooth of a mammoth was picked up on the rocky surface of Long island and sent to me. This island is narrow, thirty miles in length, and lies near the Eastmain coast, its southwestern extremity being just north of cape Jones, which is the point where James bay opens out into Hudson bay proper. It is composed of almost bare rock and has a ridge of basalt running down its center. Although it is south of the limit of timber on the mainland, no trees grow upon the island itself. At the time when mammoths lived upon the island it must have been more or less wooded in order to furnish food for them, and, from our knowledge of the uprising of the land in this region in Pleistocene times, it probably stood at a lower level, and would therefore be of smaller size.

Photographs showing this tooth in different positions were sent to Professor W. Boyd Dawkins, who had made a special study of fossil elephants, and to Professor E. D. Cope, with requests for their decisions as to the species to which it belonged. The following are their replies:

"Woodhurst, Fallowfield, Manchester, *10th July, 1882.*

"The very interesting specimen is a worn stump of an upper molar belonging to *Elephas columbi*, an animal which, in my belief, is one of the varieties of the stock from which the mammoth, Indian elephant, and *E. armeniacus* have been derived. The stump is wonderfully like some of the mammoth's in my collection, but it is narrower.

"(Signed) W. BOYD DAWKINS."

"PHILADELPHIA, *Dec. 19th, 1882.*

"I have never seen a tooth which presents all the peculiarities of this one, but each of its characters can be found separate in different teeth of the mammoth. It is probably a last deciduous molar of a variety between the typical *E. primigenius* and the smooth-plated *E. columbi*.

"(Signed) E. D. COPE."

Elephas columbi of Dr Hugh Falconer, to which this molar belongs, according to Professors W. Boyd Dawkins and E. D. Cope, has been found on the Pacific coast of Alaska.* Falconer only knew of its remains in

FIGURE 1.—*Molar of Elephas columbi from Long Island, Hudson Bay.* (½ natural size.)

the more southern of the United States and Mexico; but the present discovery, and that of a similar molar, near Edmonton, N. W. T., taken in connection with its occurrence in Alaska, shows that its range in North America was even more extensive than that of *E. primigenius*. Considering how very rare the discovery of elephantine remains of any kind has hitherto been over all that great portion of the continent between Bering strait and the vicinity of lake Erie, we may reasonably expect that among

* Bulletin of the U. S. Geol. Survey, no. 84, 1892.

future discoveries of such remains in this vast interval some at least will prove to belong to *E. columbi.*

Both *E. columbi* and *E. primigenius* may have retreated southward in America on account of the increasing severity of the climate, as did the moose and the bison, or without any sufficient change in this respect, having become accustomed to the better climate which they found to the south, they abandoned the northern regions altogether. It is to be noted that the invasion of North America by mammoths was from north to south, or in the opposite direction from the invasion of Siberia, and this circumstance may have made an important difference as to the character of their subsequent movements on the two continents and as to the latitudes in which they survived the longest in the respective regions.

Dr Hugh Falconer, who, with ample materials at his command, gave the subject very careful study, regards this elephant not as a variety of *E. primigenius*, but as belonging to a decidedly different species. Its occurrence on Hudson bay is of much interest and opens up various questions, not only as to the geographical range of the species, but also in regard to former climatic conditions of that region and the distribution of land and water at a comparatively recent period which would result from the former levels of different parts of the continent.

The accompanying figure (1) will enable those who are critically versed in such matters to judge for themselves as to the species of mammoth to which this molar belonged.

Mammoth Tooth found near Edmonton

Two or three years ago an incomplete molar, which appears to belong to *Elephas columbi,* was found in the superficial deposits in one of the banks of the North Saskatchewan river, about six miles above Edmonton, but no particulars in reference to the discovery are available. The specimen is in the museum of the Geological Survey at Ottawa. The Saskatchewan at Edmonton has an altitude of about 2,200 feet above the sea. The surrounding district is a fine agricultural country, with a deep covering of till, overlaid in parts with stratified sands, gravels, and clays, all having a rolling surface.

Elephant Remains in the far Northwest

It has long been known that mammoth remains exist in several places in the far northwestern regions of North America. Dall mentions the occurrence of bones and tusks of these animals on the lower Yukon river, and a few years ago some of their remains were purchased for the museum of the Geological Survey at Ottawa from Mr F. Mercier, who had brought them from some place on this river within the Alaskan boundary. The late Mr Robert Campbell, of the Hudson's Bay Company's service, with whom I have conversed on the subject, told me that he had found elephant bones in a river bank near the junction of the Lewis and Pelly to form the Yukon. One of these bones was sent to England and identified by Sir John Richardson as belonging to *Elephas primigenius* (Blumenbach). The late Mr Richard Hardisty and the officers of the Hudson's Bay Company have informed me that in passing along Rat river, a small tributary of the McKenzie on the west side of its delta, the Bell river, a branch of the Porcupine, and along this stream itself they have seen in various places bones of elephants projecting from the clay or other superficial deposits forming the banks. Mr Hardisty said that in the vicinity of these rivers he had frequently seen skulls of the musk-ox (often called "buffalo" in the far north) lying on the surface of the ground, mostly in swamps and partly covered with moss. This animal is not now found living west of the McKenzie river, although it is quite common over the great region to the eastward of it as far as Hudson bay and thence across the large islands lying to the northeastward, which carry its range to northern Greenland. Its desertion of the country west of the McKenzie river is one of those instances of the long-period or the final regional migrations of the larger mammals which have not yet been satisfactorily accounted for.

The late venerable Archdeacon R. McDonald, whom the writer has had the pleasure of meeting in the McKenzie valley, some years ago presented to the British Museum bones of the mammoth, the horse, and the musk-ox. I have obtained from York factory, on the west side of Hudson bay, through the kindness of Dr Percy Mathews, part of the skull of a horse which was found there half embedded in the soil; but this discovery may have no geological significance, as it possibly belonged to a domestic horse, although I could not hear of any of these animals having ever been landed at this place, although cattle for the Red River settlement and for local use have been imported to this establishment from England.

Mr William Ogilvie obtained during the present year two horns of the existing bison (which I have seen) from the auriferous gravels of Bonanza and Eldorado creeks, in the Klondike district of the Yukon near the intersection of the one hundred and forty-first meridian. From the same gravels he also obtained some coniferous wood and part of a skull and part of an antler of the reindeer. The range of the bison in modern times has not come within several hundred miles of this district.

Geological History of the Mastodon and Mammoth

The elephant family made its first appearance in the Miocene period in southeastern Asia. The earliest of the true Proboscidea were (1) the Stegodons, which were the ancestors of the mastodons, the mammoths, and the Indian elephant, and (2) the Loxodons, the ancestors of certain fossil elephants of Europe and also of the African elephant. As time went on and new species appeared, the elephants spread from their original birthplace into Europe, Africa, northeastern Asia, and thence into America over a neck of land which at a comparatively recent geological period closed up Bering strait. That such a land connection existed and that mammoths passed over it appears to be proven from the fact that remains of these animals have been found on Saint George and Saint Paul islands, of the Pribilof group, and on Unalaska, one of the Aleutian islands. The deepest part of Bering strait is covered by only 300 feet of water, and, since a subsidence of more than this amount has taken place in the Pleistocene period, there is no doubt that an isthmus connected the two continents at no distant date, and that men as well as mammoths and other animals may have walked over it. In the old world, mastodons died about the close of the Pliocene, but the American species (*Mastodon americanus*) lived on, along with the mammoth, into the human period. Falconer says: *

"Commencing with the older strata of the sub-Apennines and of the Val d'Arno and ascending to the superficial gravels or quaternary deposits of comparatively modern origin, at least four well defined species of fossil elephants have been ascertained to have existed in Europe, namely, *Elephas* (*Loxodon*) *meridionalis*, *E. antiquus*, *E. primigenius*, and *E.* (*Loxodon*) *africanus fossilis*."

A little further on the same writer says: †

"If the asserted facts be correct, they seem clearly to indicate that the older elephants of Europe, such as *E. meridionalis* and *E. antiquus*, were not the stocks from which the later species, *E. primigenius* and *E. africanus*, sprung, and that we must look elsewhere for their origin. The nearest affinity, and that a very close one, of the European *E. meridionalis* is with the Miocene *E.* (*Loxodon*) *planifrons* of India, and of *E. primigenius* with the existing Indian species."

Again Falconer writes: ‡

"The result of any observation is that the ancient mammoth of the preglacial

* Palæontological memoirs and notes of the late Hugh Falconer, A. M., M. D., vol. ii, p. 251.

† Op. cit., p. 254.

‡ Op. cit., p. 252.

'forest bed' of the Norfolk coast differs less from the later form, occurring on the banks of the Lena, than does the latter from the comparatively modern mammoth of the superficial bogs of North America, which I regard as being only a slight geographical variety of the same species."

The Extinction of Specific Forms of Mammals

From the first appearance of Proboscideans to the Recent period, one form after another has passed away, to be succeeded by another, until we have arrived at the immediate precursor of the existing Indian elephant, which appears to be specifically identical with the mammoth. Falconer insists on the importance of the fact that throughout the whole geological history of each species of elephant there is great persistence in the structure and mode of growth of each of the teeth, and that this is the best single character by which to distinguish one species from another. He finds, after a critical examination of a great number of specimens, that in the mammoth each of the molars is subject to the same history and the same variation as the corresponding molar in the living Indian elephant.* Even if zoologists agree that these two elephants belong to the same species, *E. primigenius* is sufficiently distinguished as a well marked variety to deserve recognition for all the purposes of geological description. No single cause may account for the extinction of the mammoth all over the world. As will be pointed out further on, it may have been due to the climatic changes in Siberia, while human agency may have been the final cause in Europe and North America; but whether the Indian elephant is specifically identical with *E. primigenius* or not, there appears to be at the present time a general tendency to extinction in the existing form, as one which has run its course. The cause of this is not apparent, unless it be owing to the well known general law that the higher species of animals have a shorter term of existence than the lower ones, and that the period of their survival is somewhat proportionate to their rank in the scale of being.

The history of the larger mammals shows that when the geographical range of a species has become greatly diminished, with a corresponding reduction in its numbers, it does not recover lost ground, but hastens to its end. These conditions now apply to the Indian elephant, whether he represents the very circumscribed remnant of the once almost cosmopolitan mammoth or not. Another sign of the approaching extinction of this species is its loss of reproductive vigor, as evidenced by the fact that it will scarcely breed at all in the state of domestication.

As the mammoth lived contemporaneously in the old and new worlds

* Op. cit., p. 168.

after the Glacial period, there could scarcely have been a sudden change in climate or conditions which would account for its disappearance in both hemispheres about the same time. The Indian species maintains its existence in the original home of the whole race because the conditions favorable to Stegodont elephant life probably continue to be better there than anywhere else.

Migrations of northern Mammals

Popular writers on this subject appear to associate the existence of entire carcasses of mammoths about the mouth of the Lena river with the extinction of the species all over Europe, Asia, and North America, whereas this fact is only a local circumstance in the long history of the animal.

The migration of birds and mammals, which is so characteristic of many species at the present day, has been going on for ages. The alternation of the seasons in the northern hemisphere would naturally stimulate and develop a tendency among such creatures to move northward and southward with the changing temperature and food supply, and the elephants would be no exception. The reindeer, with whose bones those of the mammoth are associated in Europe and Asia, retains its migratory instincts in both the old world and the new.

But the woodland variety of this species (called the caribou in Canada) is not migratory, and it is possible and even probable that there were also migratory and non-migratory mammoths, according as they inhabited (like the reindeer) the open northern barren lands or the more southern wooded country in either the old or the new world. The musk-ox and the American bison made extensive annual migrations. The Arctic fox travels hundreds of miles north and south every year with the change of the seasons. The Canada lynx is one of the most migratory of North American mammals, but its movements are governed by food supply alone, and depend upon the varying abundance or scarcity of its principal prey, the common American hare. Even the little lemmings perform wonderful migrations, impelled, as it were, by an irresistible impulse.

The moose or American elk (*Alces americanus*) migrates slowly from one large area to another through periods extending over many years. For example, in the Gaspé peninsula the last interval between its leaving and again returning to the same district was upward of half a century, and in the region between the upper Great Lakes and James bay the period between his last withdrawal and reappearance has been still longer. Within the historic period the bison roamed as far east as lake Superior and lake Erie, and in modern geological times it ranged into the distant northwest as far as the Yukon river, where, last year, Mr William Ogilvie obtained two of its horns (which I have seen) in the gold-bearing gravel of Bonanza creek, in latitude 64°. The biche or red deer (*Cervus canadensis* Erxleben) inhabited the St. Lawrence valley eastward to the outlet of lake Ontario in comparatively recent times, its remains in a good state of preservation having been found embedded in shell marl in at least two localities near Kingston, and also in the sand and gravel of Burlington Heights at a depth of 30 feet from the surface and at a height of 77 feet above lake Ontario. Thirty years ago it was common in eastern Manitoba, but now it has retreated still further west. Such examples as the foregoing of annual and long-period migrations favor the supposition that the mammoth, in addition to its slower general movement of dispersion to remote parts of the earth, made annual migrations in regions where such movements would be beneficial to him and might naturally be expected, as in northern Siberia. The average distance at the present day between the verge of the forest in northern Europe and Siberia and the coast of the Arctic sea is from 100 to 250 miles.

Even if the distance had been as great as this at the time when the mammoth inhabited these regions, which is not probable, this animal could easily move from the forest to the sea coast and back again between spring and autumn. But there is evidence that the modern forest-line has been retreating southward in both the old and new worlds. This tendency has prevailed for a great length of time, as is shown by the remains of trees of existing species on the coasts of Bering strait beyond the present limits of timber, and in Melville island off the northern coast of this continent, the latter occurring between 500 and 600 miles directly north of the nearest trees now growing on the Coppermine river and near Great Bear lake. The increased severity of the seasons in Greenland in historic times is another evidence of the deterioration of the subarctic climate, which appears to have this tendency all round the world, with perhaps a few local exceptions, as in one part of northwestern Alaska, due probably to a favorable change in the ocean current there.

Extinction of the Mammoth in Siberia

The mammoth in northern Siberia probably passed the winters within the forest-line, where he would find shelter from the chilling winds and where he might live well, browsing on the small branchy spruce, larch, birch, etcetera. With the advent of spring he would begin his northward march, taking advantage of the long daylight, and he would spend part of the summer and the autumn roving about the shore of the Arctic sea, enjoying the cool weather and finding abundant sustenance on the small trees and the alder, willow, and birch brushwood. Then, with the beginning of the severe weather, he would turn his footsteps toward his winter quarters and move south as the season advanced. The periods of their annual migrations having become settled, it would be difficult or impossible to overcome the inertia of long-fixed habit, and they would be obliged to endure the increasing severity of the climate on the borders of the Arctic sea. In the meantime their numbers would be greatly diminished from causes to be mentioned further on. At length, those which journeyed as far as the sea coast might be reduced to the single herd which migrated to the mouth of the Lena, where the climate of autumn would be the best on the coast, owing to the large quantity of warm water from the south which accumulates off the mouth of this great river.

At this stage, if an unusually early and severe season were to set in, accompanied by great snow-storms, before the herd had started for the south, the result might be disastrous to the remaining mammoths. The now stunted brush would be covered by the deep snow, on which perhaps a strong crust had formed, thus preventing the animals from obtaining any food, while the almost continuous darkness of the early winter would also operate against them. The same conditions would make it difficult or impossible for them to travel. Other individuals or herds which did not migrate so far north may have perished from a similar cause in various parts of the region. We know how completely helpless the deer of any species become in our northern woods when caught in deep snow with a crust upon it.

Under circumstances like these the last of the mammoths would soon perish, since creatures of their organization, living upon such slightly nutritious food, must have it continuously and in large quantities. That such a process of starvation is not imaginary, I may mention the fact that the reindeer sometimes perish over large areas in our northern barren-lands from this cause. Their lives depend upon a continuous supply of the reindeer-lichen, which they obtain by removing the snow or by finding the plant where the ground has been left bare by drifting. A striking instance of this occurred many years ago on Akpatok island, in Ungava bay. This large island had always swarmed with reindeer, but one winter, when the snow was deeper than usual, rain fell upon it (an almost unprecedented occurrence) and formed a heavy and permanent crust over both the bare ground and the snow, thus preventing the deer from obtaining their food. The consequence was that the whole number perished, and the island has never been restocked. If this former great herd had comprised the whole species then living, the reindeer would now be extinct.

Preservation of the Flesh of Mammoths in Siberia

The preservation till the present day of the flesh of some of the mammoths which perished in the region about the mouth of the Lena river and elsewhere proves that the carcasses must have become frozen immediately after death, and this circumstance may be accounted for in the following way: If the last of these creatures succumbed in the manner supposed, there may have been at that time a series of unusually cold years, as sometimes happens in high latitudes, and this, together with the increasing severity of the climate in general ever since, would account for the preservation of some of their carcasses in the snow and ice which have persisted in that region till the present time.

The occurrence of large numbers of the remains of mammoths in the alluvial deposits about the mouth of the Lena and other rivers may be explained by the supposition that the animals had broken through the too thin ice in attempting to cross the streams upon it on their southward migration in the autumn, and that their bodies had subsequently floated down to the still water. Indeed, it is highly probable that whole herds of these animals lost their lives in this manner. While the bison was abundant in our northwest territories it was a matter of common occurrence for large numbers of them to be drowned when attempting to cross the streams in compact droves before the ice was strong enough to bear the strain. The great abundance of bison bones in some of the fluviatile deposits in this region is easily accounted for in this way.

The mammoths, owing to their great weight, would be still more liable to such an accident. Professor Richard Lydekker, in "The Royal Natural History," lately published, speaking of the trade in ivory from Siberia, says that within a recent period, covering twenty years, 20,000 mammoths must have been discovered in that region.

Improbable Theories

The supposition that the mammoths of northern Siberia were frozen where we find them by a sudden change from a warm to a very cold climate, and which has remained permanently so, is as untenable as the other theory, which supposes the bones and tusks found there to be those of mammoths which were drowned in great numbers and at the same time within a limited area by a sudden cataclysm. If it were possible (which it is not) that such an abrupt change of climate could happen, it would require to be general around a great part of the globe, and there is no evidence that such a thing occurred at any time in the history of the earth. Again, to invoke the agency of sudden cataclysms to account for geological phenomena is an exploded notion which does not require discussion.

Food and geographical Range of the Mammoth

From the remains of food found with the teeth and skeletons of the mastodon and mammoth, it has been pretty satisfactorily ascertained that in North America both of these animals subsisted largely on the twigs and boughs of northern trees, such as the spruces (*Picea*) and white cedar (*Thuja occidentalis*), together, probably, with those of other northern trees and bushes, and no doubt the food of the Siberian mammoth was of the same nature. Their large grinders and powerful muscles were admirably adapted to reduce such materials to a pulp. Both the African and Indian elephants are "coarse feeders," living principally upon the branches and bark of trees and bushes, and the mammoth, wherever he wandered, would require to subsist upon such kinds of food of this description as the country he might be in produced.

"We further know that when the mammoth pastured along the margins of the great swamps of Ohio and Kentucky the vegetation then was nearly identical with what it is now, being very different from that of Siberia" (Hugh Falconer). The same writer,* referring to *Elephas primigenius*, says of it: "A scope in space and time, taken together, has been assigned without a parallel, I believe, within the whole range of the mammalia, fossil or recent. D'Archiac, in his excellent 'Histoire des Progrès,' so late as 1848, gives a brief summary of the localites in which the remains of the mammoth (*E. primigenius*) have been said to occur, namely, from the British islands across the whole of the temperate zone of Europe and Asia and along all the coasts and islands of the Icy sea as far as the frozen cliffs of the east coast of Bering strait, in Eschscholtz bay, in Russian America as high as 66° of north latitude, over most of the United States of America, in the great valley of the Mississippi, and along the coasts of the gulf of Mexico. De Blainville, going a step beyond most of the paleontologists, doubtingly referred the fossil remains of elephants found so abundantly in tropical India to the same species, thus assigning at least half of the habitable globe for the pasture ground of the mammoth."

Woolly Coat of the Siberian Mammoth

The wool and long hair found upon the Siberian mammoths prove

* Palæontological memoirs and notes of the late Hugh Falconer. London, 1868, vol. ii, p. 77.

that they had been accustomed for a great length of time to a severe climate. Although the Indian elephant inhabits a warm country, it is a well known fact that he is intolerant of great heat and suffers much when exposed to the direct rays of the sun in that climate. In the wild state he seeks the cool shade and wanders about at night or in the early morning.

Notwithstanding the heat of the climate of India, it has lately been discovered that the elephant of that country retains traces of wool like that which formerly clothed the mammoth. The presence or absence of wool or of a thicker or thinner coat of hair or fur on a mammal does not often constitute an important specific character. On the highlands of Tibet, where the climate is cold in winter, the domestic goat and the mastiff dog produce fine wool under their hair. In Canada we have examples of the same kind of growth in at least two of our common mammals; the moose and the porcupine. In the country on the south side of the Saint Lawrence, below Quebec, I have seen quantities of very fine brown wool taken from beneath the hair of moose killed in the middle of winter, which the French Canadian women were manufacturing into stockings and mittens of a superior quality. The porcupine ranges far north, and in the region west of Hudson bay he is covered in winter with a very deep coat of wool, through which his quills and long coarse hairs project but a short distance. Further south these animals have little or no wool, and in the hot weather I have occasionally seen them entirely destitute of both hair and quills, their naked black skins resembling that of a Chinese dog.

Disappearance of the Mammoth from Europe and America

The mammoth lived in Europe before the Glacial period, and he probably had a wider range in the same continent after that epoch. His final extinction in this region may have been due to human agency. As population increased and the forests became traversed in all directions by highways, and after wide spaces had been cleared by different races of men, the mammoths would find it difficult to maintain their footing. They do not appear to have ranged into Norway or to the southward of the Pyrenees and were very rare in Scotland and Ireland. The geographical boundaries at that time of certain kinds of trees which they preferred for food may have been the cause of thus limiting their distribution.

In North America the last of the mammoths may have been killed off by the aborigines. There is evidence that they hunted these creatures, and no doubt they did so for food. Such a large animal would always be a tempting object of the chase to a people depending for subsistence almost entirely on the product of their hunt. When we see that a few years of shooting by foreign sportsmen in Africa has reduced the elephants of that great continent to a mere fraction of their former numbers, it is not unreasonable to suppose that systematic hunting by the North American Indians throughout many centuries would finally exterminate the mammoth on this continent.

Habitat of the Mammoth inferred from the Form of his Tusks

In both Asia and North America the mammoth probably preferred the open barren-lands or tundras to the thick woods, and in this connection the occurrence of its remains in Alaska, the Yukon and McKenzie River region, in the far northwest of Canada, and on the east coast of Hudson bay is of much interest. The great length and the complete curve of the tusks of these animals show that they were only fitted for traveling in such regions or in very open woods. They would be able to make little or no progress through the thick coniferous forests of Siberia or Canada.

In 1884 I observed on Nottingham island, in Hudson strait, a curious fact bearing on this question in connection with the antlers of the reindeer. On the mainland, where these deer may require to traverse the thick forest in some part of their migrations, their antlers, although much larger and longer than those of the woodland reindeer or caribou, are straight at the tips and of such a form as to be readily dragged through the branches of trees; but on the large island referred to there are no trees of any kind and the antlers of the deer are more spreading, while the tines are strongly curved or hooked. These peculiarities may be merely ornamental or they may be of service to the animal in some other way, but it would be impossible for him to get through any forest. The peculiarities of the tusks of the mammoth, which have been already referred to, would not only prevent the creature from traveling in thick woods, but they would also render the tusks useless for digging up trees, which is the principal use to which both African and Indian elephants put their straighter tusks. These characters would also indicate that the mammoth was adapted only for living where it was not necessary to dig at the roots of trees and to pull them down, but in some region where he might obtain all the brush he required, as he could on the extensive northern plains of both continents in summer, as well as among the small branchy trees at the edge of the forests in winter. The fact that in this habitat the ground would be frozen for the greater part of the year is another reason why he would not use his tusks for digging.

The Occurrence of Mastodon Remains near the southern Extremity of James Bay

When at moose factory, at the southwestern extremity of James bay, in the autumn of 1877, I was presented by Mr S. K. Parson, the chief factor in charge, with a very perfect tooth of a mastodon, which had been obtained shortly before my visit in the bed of the Moose river, at its first bend below the junction of the Missinaibi and Mattagami to form this trunk stream. The locality is 46 miles in a straight line southwestward from moose factory and has an elevation of about 150 feet above the sea. In the middle of summer of that year, the stream was very low, and an Indian passing down in his canoe happened to see a very large bone, which turned out to be a mastodon's jaw, lying in the shallow water. Setting it on end beside his canoe, he chopped out this tooth with his hatchet, and then allowed the jaw to drop back into the river. The molar is of a medium size and is very well preserved. It has nine conical points or tubercles, all of which are entirely covered with enamel. At the same time that I obtained this tooth I was informed by Mr Parson that some years previously a party of Indians had found some large bones in the bed of the Abitibi river, between the lowest on Sextant rapids and its junction with Moose river, which occurs at 18 miles above Moose factory. From the description, I judged them at the time to be elephantine remains. The Sextant rapids are at the upper end of the first stretch of the Abitibi river after leaving its mouth. The superficial deposits are of the same character along this stretch as on the main Moose river for many miles above and below the junction of the two streams.

The Pleistocene Deposits southwest of James Bay

In order the better to surmise the conditions and the geological time of the existence of the mastodon in the region around the southern extremity of James bay, I should here give a short description of the Pleistocene deposits and of the general character of the district.

Quaternary clays containing recent marine shells extend as far, at least, as the Sextant rapids, and fragments of lignite washed out of these deposits were observed along the margins of the river in this section.

The upward general course of Moose river, which is continued by the

Missinaibi, from Moose factory,* which stands about 7 miles in from the mouth, is southwest for 127 miles to Round bay, at the foot of the Archæan plateau, where it turns south. The rate of rise in the river-bed from the head of tide, 9 miles above Moose factory, to this point is estimated to be between 3 and 4 feet to the mile, which would make the elevation at the end of this distance between 400 and 500 † feet above sea-level. In this interval the river flows with a pretty uniform and rather swift current, interrupted by stony rapids here and there. The banks consist exclusively of till and stratified drift, resting directly upon Silurian and Devonian limestones, which slope almost imperceptibly toward the bay or at only about the same rate as the river-bed itself.

The name Moose river belongs properly to only the trunk stream below the junction of the Missinaibi, or western branch, with the Mattagami, or central branch, at the above mentioned 46 miles from the factory; but as the traveled route to the Canadian Pacific railway follows the former branch, it is sometimes referred to under the same name. The general height of the cut-banks of the river increases from 10 or 20 feet at Moose factory to about 140 feet at the end of the 127 miles referred to, but often for considerable distances the country is low on one side or the other, and sometimes on both sides. The usual height of the cut-banks is from 30 to 50 or 60 feet. Their lower parts appear to be composed, in most cases, of blue clay, sometimes soft and sticky, with or without rounded pebbles. The central stratum, which constitutes the major portion of the banks, consists of bluish-gray and drab clays, with boulders and pebbles. The marine shells washed out of the banks appear to be derived from beds of pebbly drab clays associated with this division. The upper portions of the deposits consist of beds of gravel and sand, with brownish gravelly and bouldery earth towards the top.

The clays near the mouth of the river contain upward of a dozen species of marine shells, some of which indicate tolerably deep water; but in ascending the stream the deep-water species disappear, and at last only the shore and the shallow-water shells remain, such as *Saxicava rugosa*, *Macoma calcarea*, *M. grœnlandica*, *Mytilus edulis*, and *Mya truncata*. Some of these shells were found as far as Round bay, at the extremity of the long southwestward stretch of the river above referred to. Marine shells were also observed along the Mattagami from its mouth up to the foot of the Grand rapids, a distance of 39 miles, and at an altitude which is probably only a little lower than that attained by these shells on the Missinaibi. The species last seen on the Missinaibi were *Saxicava rugosa* and

* Factory, the residence of a chief factor or agent.

† In my Geological Survey Report for 1877, p. 7 C, a lower estimated elevation was mentioned, but subsequent observations render it probable that this is more nearly correct.

Macoma fragilis (*Tellina grœnlandica*). These, with a *Leda*, were also the species observed at the highest localities on the Mattagami. Along the Albany river, which flows into the western side of James bay, and also on its great southern branch, the Kenogami, the banks, as well as the deposits of which they are composed, are similar to those of Moose river and its branches. I estimated the elevation of the highest and most inland locality at which I found marine shells on the Kenogami to be 450 feet above the sea.* The Attawapiskat is the largest river flowing into James bay north of the Albany. I surveyed this stream for upward of 300 miles from the sea, and although it flows through a level country and has low banks, I did not detect marine shells at any great distance from the head of tide.

Although the existence of lignite *in situ* in the superficial deposits of the Albany and Abitibi rivers may be inferred from the occurrence of loose pieces of it along their shores, beds of this substance have as yet been noticed only on the Kenogami and the Missinaibi. On the former stream it was found in the bottom of an old channel excavated in the till and again filled up by boulder clay.† This bed contained sticks of coniferous woods and of the canoe birch, but no animal remains were detected in it.

Along the Missinaibi, beds of lignite were seen at a number of places all the way from the foot of the Archean plateau to the junction of the Mattagami. The first of these was in the west bank of a southern branch called Coal brook, three-quarters of a mile from the main river. This bed is three feet or more in thickness, is underlaid by soft sticky blue clay, and overlaid by about 70 feet of till, full of small pebbles, passing into gravel at the top. This lignite contains a little iron pyrites, and much of it retains a distinct woody character. Some of the flattened trunks embedded in it are two feet in diameter.

"On the south side of the river, at nineteen miles below Coal brook or two miles above Woodpecker island, a horizontal seam of lignite was found in the midst of a bank of till 125 feet high. It is from 1½ to 2½ feet thick, and is made up principally of sticks and rushes. Below the lignite are 80 feet of yellow-weathering gray clay and above it 45 feet of blue clay. Both varieties of clay are full of pebbles, and they also hold some striated boulders of Laurentian gneiss, Huronian schists, and unaltered Devonian limestone.

"At three miles below Woodpecker island, or nine miles above the mouth of Opazatika river, another bed of lignite occurs in the bank on the same side. It is six feet thick, but diminishes to the eastward, and is of a shaly character, being made up of laminæ of moss and sticks. Immediately beneath the lignite is a layer

*Geological Survey Report for 1871-'72, p. 112.
†Geological Survey Report for 1871-'72.

one foot thick of irregularly mingled clay and spots of impure lignite. Next below this are 40 feet of unstratified drift, full of small pebbles, under which are a few feet of stratified yellowish sand and gravel. Resting upon the lignite are five feet of hard lead-colored clay, with seams and spots of a yellow color and layers of red, gray, drab, and buff. Above all and forming the top of the bank, 65 feet high, are 10 feet of hard drab clay, with striated pebbles and small boulders and holding rather large valves of *Saxicava rugosa*, *Macoma calcarea* (*Tellina proxima*), and *Mya truncata*. Small seams of lignite were seen in two places in the bank on the same side at and again half a mile below the foot of a rapid which occurs about six miles above the Opazatika.

"In the interval between one and two miles above this stream the whole bed of the river appears to be underlaid by lignite. When sounded with a heavy pole, it has an elastic feel and gives off large volumes of gas, which may also be seen at any time bubbling up spontaneously here and there all along this part of the river. This phenomenon has been observed by the Indians from time immemorial, and the locality has received the name of 'The Bubbling Water.'" *

At the foot of the long portage on Missinaibi river, which is four and a half miles within the Archean border, or that distance south of Round bay, at the head of the long southwestward stretch above described, there is a considerable thickness of fine silt in thin layers, with moss and remains of fresh-water marsh plants between most of them. The mean height of the deposit is about 90 feet above the level of the highest occurrence of the marine shells before mentioned, or probably about 550 feet above the sea. At the time of the postglacial submergence this deposit may have been forming at what was then the mouth of the Missinaibi river, while the whole of the Paleozoic plain between it and James bay was covered by the sea.

The deposits which have been described cover a very extensive district, namely, the low country embraced by a semicircular curve in the great Archean plateau, extending 200 miles southwest from James bay. This tract is all underlaid by the nearly horizontal Silurian and Devonian strata already mentioned. These rocks also appear to form the floor of the bay itself, which is 300 miles long and 150 miles wide.

The lignite beds above described probably all belong to basins of limited extent. The one which has been referred to as occurring in the bottom of a drift-filled valley which had been excavated in older till on the Kenogami river, and also most of the beds along the Missinaibi, are of interglacial age. The seam which has been mentioned as lying beneath a thick stratum of till on Coal brook may be of preglacial age, in which case the blue clay below it would also be preglacial. Some of the higher beds of impure lignite further down the Missinaibi may be post-

*Geological Survey Report for 1877-'78, p. 4 C.

glacial. The stratified deposits with which the lignites are associated are, in part at least, marine, as proved by the shells which they contain.

PERIOD WHEN THE MASTODON LIVED HERE

The mastodon's jaw described above, having been found loose in the bed of the river, may have been washed out of these banks and thus be of either interglacial or postglacial date; but it had not suffered any wear, the tooth being fresh and perfect, and it shows no sign of abrasion. It has been mentioned that lignite occurs *in situ* in the bed of the river where the jaw with this tooth was found.

This relic of the mastodon may belong to a very recent period, perhaps to a time subsequent to the excavation of the river channel out of these lignite-bearing clays, sands, and gravels. Its most ancient possible date would be subsequent to that of the lignite bed on which it rested.

MASTODON REMAINS FOUND IN MANITOBA

Some years previous to 1853 parts of the skeleton of a large mammal, which afterwards proved to belong to a mastodon, were found by Indians in the bottom of the valley of Shell river, at its junction with its east branch. This stream is itself an eastern branch of the Assiniboine, and it takes its rise in the high ground to the west of lake Winnipegosis. The river-flat at the spot where the mastodon remains were found has an elevation of 2,050 feet above the sea, according to Mr J. B. Tyrrell.* The scapulæ were the only portions of this skeleton which reached England, and they were examined by Sir John Richardson, who at first gave the species to which they belonged the provisional name of *Elephas rupertianus*, but afterwards, on making critical comparisons with the bones of other fossil elephants, he wrote:

"The probability, therefore, is that the Swan river (*i. e.*, Swan River district) bones belonged to the *Mastodon giganteus*, and that the range of that species must be extended northward in Rupert's land to the fifty-second parallel of latitude, while the provisional geographical designation of *Elephas rupertianus* must be expunged." †

DEPOSITS IN WHICH THE MASTODON BONES WERE FOUND

In 1874 I examined the Assiniboine river all the way from Fort Pelly to Fort Ellice and also a part of Shell river, and sent my assistant, Dr

* Report of the Geological Survey of Canada for 1890–'91, p. 129 E.

† Zoology of the Voyage of H. M. S. *Herald* during the years 1845–'51. London. Lovell Reeve, 1854, pp. 101, 141.

J. W. Spencer, further up the latter stream. As the age of the deposit in which these mastodon remains were found and the nature of the surrounding country were important in connection with the discovery, I quote Dr Spencer's report to me on these points: *

"The valley of the Assiniboine adjacent to that of the Shell river is about a mile wide and some 200 feet deep. The alluvial flat at the bottom of the valley is three-quarters of a mile wide, and the banks rise steeply on either side. Through this level flat the river pursues a meandering course from side to side, occasionally leaping a small rapid caused by the obstruction of Laurentian boulders. Twenty miles further up, the valley is nearly 3 miles wide, but at this place, in the bottom and following the valley longitudinally, there are 4 or 5 series of hills, rising irregularly one above the other, till the highest reaches nearly to the level of the plain above. Between these hills there are small deep valleys. The western bank is often strewn with gravel and boulders, while the flats below are nearly free from them, excepting in places along the bed of the river. The sides of the valley are often deeply gorged, but the ravines do not extend to any great distance back from the valley. Many of them appear to have been cut out by the waters from springs. These springs usually hold a considerable quantity of iron in solution, and I observed several places where yellow ochre was being deposited around them. In several localities on the banks of the Assiniboine extensive landslides are to be met with, sometimes showing stratified deposits of clay or sand. The general course of the Assiniboine river at the influx of the Shell river is nearly south, but above this it has a more westerly direction.

"I explored the Shell River valley upward for 30 miles, and Mr Hagar continued the exploration for 10 miles further. Along the upper part of this distance the country on either side has usually a rolling prairie character, while in the lower portion the river flows in a valley nearly as wide and deep as that of the Assiniboine. The general course is nearly from the north. At the bends of the valley the river usually winds its way to the outer side, and on the inner side of the curve there is left a terrace or series of terraces rising from the alluvial flat to the plain above. The country is generally wooded, except here and there where fires have swept over small areas. The Shell river is much more rapid than the Assiniboine, and the sides of the valley are much more deeply gorged than those of the latter river. At the landslides along the Shell river I observed a few stratified deposits, but they generally showed only a heterogeneous mixture of gravelly earth, with boulders. . . .

"If the rivers which now flow through them have excavated these valleys, the former must be of great antiquity. The valleys are yearly becoming larger by the spring floods bearing away great quantities of material. Everywhere along the river banks there are evidences of former landslides. . . . The deposits of the Shell River valley frequently consist of irregular beds of clay, with boulders, while along the alluvial flat of the Assiniboine they consist of regularly stratified clays. The summits and sides of the banks of both streams are generally covered with boulders.

"In the more recent deposits of the Shell River valley an Indian is said to have found, a few years ago, some large bones, which were at the time sent to Fort

* Report of the Geological Survey of Canada for 1874–'75, pp. 58 and 63.

Ellice and afterwards to England. These remains were described to me by a man who had seen them, and also the place whence they came. They appear to have been large enough to have belonged to *Elephas*." . . .

In the summer of 1887 Mr J. B. Tyrrell, of the Geological Survey, made a further examination of Shell river, the results of which are published in the Report of the Department for 1890–'91. Referring to these bones, he says:

"The Indians allege that at this point (the junction of the north and east branches) huge bones were found at the bottom of a landslide and were brought to the officer in charge at Fort Pelly, by whom they were forwarded to England. Hon. W. J. Christie, of Brockville, Ontario, who was in charge of Fort Pelly at the time, informs me that the bones were shoulder-blades, and that in 1853, some years after the bones were brought in, he visited the place 'and examined the spot carefully where the blades were taken out of the river at low water. A land-slip had occurred from the bank and carried the bones into the river. I found, from cross-questioning my guide, that the Indians had collected the bones and burnt them on the bank, from superstition, and buried what would not burn. I examined the spot where they had buried the bones, but what remained crumbled to pieces when touched.' " *

When traveling in the Northwest territories in 1873 I was informed that large bones, supposed to be those of elephants, had been found at Sand Hill lake, near the elbow of the South Saskatchewan river, and also on the surface of the ground on White Mud river, a small tributary of the Missouri on the west side of the Cypress hills,† but I have never been able to verify these reports.

Discoveries of Elephant Remains in other Parts of Canada

Numerous discoveries of remains of both mammoths and mastodons have been made at various times during the past seventy years in the province of Ontario, but with one exception they all occurred in the district south of a straight line drawn west from Toronto to the outlet of lake Huron. The exception was the finding of the greater part of the skeleton of a very large mammoth in a swamp on lot 9, range VII, of the township of Amaranth, county of Wellington, at about 50 miles northwest of Toronto. A tusk found with this skeleton was reported to measure 8 inches in diameter and 14 feet in length.

In Ontario the remains of the above animals have always been found under similar conditions and in very recent deposits. In a few instances they have been met with in gravel and sand. At Burlington heights, at

† Report of the Geological Survey of Canada for 1873, pp. 73, 74.
* Op. cit., p. 129 E.

the western extremity of lake Ontario, the bones and tusks of a large mammoth were found in 1848 in an ancient beach deposit, 37 feet below the surface and at an elevation of 70 feet above the lake; but in the majority of cases such remains have been discovered just beneath the surface of the ground in cutting ditches to drain swamps, in shell marl left by the drying up of small shallow lakes, or under thin coverings of superficial loam, silt, etcetera. In the province of Quebec no traces of fossil elephants have yet been recorded, as far as the writer is aware.

In the maritime provinces the only discoveries of such relics yet made consist of some mastodon bones which were found in banks of sand and gravel in the valleys of Middle and Baddeck rivers, in the central part of the island of Cape Breton, which forms part of Nova Scotia. The elevation in each case did not extend 50 feet above the sea, and the two localities are less than 20 miles apart.

NOTE.—Since the foregoing paper was in print the writer has received the June number of the Scottish Geographical Magazine, containing Professor James Geikie's thoughtful article on "The Tundras and Steppes of Prehistoric Europe," in which he makes some remarks that are of interest in confirmation of the manner in which I have supposed that some of the mammoths of Siberia had perished. He says: "We have seen how in existing tundras and steppes the semi-domesticated and wild animals of these regions are now and again overwhelmed in storms and smothered in snow. Now, similar catastrophies must have happened again and again in the tundras and steppes of prehistoric times."

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 9, PP. 391-460, PLS. 27-29 DECEMBER 1,* 1898

PROCEEDINGS OF THE TENTH ANNUAL MEETING, HELD AT MONTREAL, CANADA, DECEMBER 28, 29, AND 30, 1897

HERMAN LE ROY FAIRCHILD, *Secretary*

CONTENTS

SESSION OF TUESDAY, DECEMBER 28

The Society was called to order by President Edward Orton at 2.30 o'clock p m, in the lecture-room of the Peter Redpath Museum, McGill University. Mr George Hague, of the Board of Governors of McGill University, made a felicitous address of welcome, to which President Orton made a brief response.

*Although this brochure was issued as a whole at this date, pages 401 to 452 were printed and distributed in July.

The administrative business of the session was introduced by the report of the Council, which was submitted in print as follows:

REPORT OF THE COUNCIL

To the Geological Society of America,
in Tenth Annual Meeting assembled:

The Council has held but one meeting during the past year. No meeting was held at Detroit, with a quorum, as three of the officers were in Russia at the International Geological Congress, and all the Councilors were in the field or otherwise prevented from attending. The determination of matters essential to the Winter meeting was made by the President and Secretary in conference with other Fellows of the Society and by subsequent correspondence of the Council (see By-Laws, chap. ii, sec. 7).

It seemed desirable that a Librarian should be named to receive and acknowledge the geological literature which is presented to the Society, to have more immediate supervision of the library than the Secretary could give, and to be in frequent communication with the officers of the Case Library. Fortunately the Society has in Cleveland an excellent representative, and acting under the discretion given in the Constitution, article iv, section 6, the Council has recommended the election of a Librarian and has nominated Professor H. P. Cushing.

The Society continues to grow in numbers and influence and is prosperous in every way. The continued financial depression has not apparently affected the sale of the Bulletin or the condition of the Treasury. The details of administration are shown in the following reports of the officers:

Secretary's Report

To the Council of the Geological Society of America:

Meetings.—The Summer meeting, held at Detroit, Tuesday, August 10, occupied for that day the time and place of Section E, American Association for the Advancement of Science. The program was covered in the one day. This plan of dividing time with Section E was much more satisfactory than the experiment tried the previous summer, of holding only an executive session and reading all papers by title. The plan was satisfactory both to the Society and to the Association, and it is understood that the same will be followed at the next meeting.

Membership.—We have lost two Fellows by death, Joseph F. James, who died March 29, and Edward D. Cope, who died April 12. The last printed list (April, 1897) included the names of 233 Fellows. Nine names of Fellows elected at the Summer meeting must be added to the roll, as follows: R. E. Dodge, C. R. Dryer, W. C. Knight, C. F. Marbut, H. F.

Osborn, E. C. Quereau, G O. Smith, W. G. Tight, and J. A. Udden. This gives a total membership at this date of 242. Several Fellows are liable to be dropped from the roll for non-payment of dues, and there are four candidates now before the Society.

Distribution of Bulletin.—The distribution for the year is included in the following table:

DISTRIBUTION OF BULLETIN FROM THE SECRETARY'S OFFICE DURING THE YEARS 1891–1897

Complete Volumes

	Vol. 1.	Vol. 2.	Vol. 3.	Vol. 4.	Vol. 5.	Vol. 6.	Vol. 7.	Vol. 8.
Distributed to Fellows	..	..	209	214	214	223	222	231
Donated to "exchanges"	91	91	89	89	89	87	85	85
Sold to libraries	87	87	89	85	80	86	79	75
Sold to Fellows	22	15	9	5	3	2	1	....
Sent to Fellows, deficient	2	1	1	....	....	....	....	....
Donated	4	4	3	2	2	2	1	1
Bound for offices and library	3	3	3	3	3	3	3	3
Volumes in reserve	55	305	347 (?)	352 (?)	343 (?)	97 (?)	109 (?)	105 (?)
Complete volumes received	264	506	750 (?)	750 (?)	734	500 (?)	500 (?)	500 (?)

Brochures

	Vol. 1.	Vol. 2.	Vol. 3.	Vol. 4.	Vol. 5.	Vol. 6.	Vol. 7.	Vol. 8.
Sent to Fellows, deficient	48	132	46	43	26	11	12	5
Sent to libraries, deficient	..	7	4	3	1	1	3	5
Sold to Fellows	16	20	8	13	17	7	2	2
Sold to the public	12	15	16	13	7	11	6	6
Donated	3	3	3	3	2	....	....	....

Subscriptions.—The list of libraries subscribing to the Bulletin was printed in the former report. To that list is added seven libraries which have subscribed during the past year, as follows:

Cambridge—Radcliffe College (brochures).
Columbia—South Carolina College.
Harrisburg—Pennsylvania State Library.
Newark (New Jersey)—Free Public Library.
Philadelphia—University of Pennsylvania (brochures).
Sacramento—California State Library (brochures).
West Point—United States Military Academy.

This makes a total of 72 permanent subscribers. There are probably several other libraries which are keeping a file of the volumes, but their orders have been through dealers or irregular and have not been placed in the above list. All of these 72 subscribers have purchased the entire set of eight volumes. As the number of volumes and the cost of the set increases (now $40), it will be proportionately more difficult to place full sets. However, there are a large number of state libraries and other strong institutions which will be compelled by the public demand to place the entire Bulletin upon their shelves.

Bulletin Sales.—In the previous report it was noted that the receipts for 1896 exceeded those of any former year, being $695.75. It is gratifying to report that the receipts for the past year are $772.05. The average cost of the eight volumes has been about $1,800. The amount which can confidently be expected as an annual income from the sale of the Bulletin is already equal to one-third of the annual cost.

RECEIPTS FROM SALE OF BULLETIN DURING 1897

By Sale of Complete Volumes

	Vol. 1.	Vol. 2.	Vol. 3.	Vol. 4.	Vol. 5.	Vol. 6.	Vol. 7.	Vol. 8.	Total.
From Fellows............	$13 50	....	....	....	....	4 00	$8 00	....	$25 50
From libraries...........	50 00	$50 00	$55 00	$55 00	$50 00	$50 00	60 50	$320 00	690 50
Total for 1897.....	63 50	50 00	55 00	55 00	50 00	54 00	68 50	320 00	716 00
By last report (1896)...	470 60	458 50	433 50	397 50	372 00	389 00	325 00	50 00	2,896 10
Total to date.....	$534 10	$508 50	$488 50	$452 50	$422 00	$443 00	$393 50	$370 00	$3,612 10

By Sale of Brochures

	Vol. 1.	Vol. 2.	Vol. 3.	Vol. 4.	Vol. 5.	Vol. 6.	Vol. 7.	Vol. 8.	Total.
From Fellows............	....	....	$1 05	....	....	$0 60	$0 20	$0 90	$2 75
From public..............	$0 40	$1 70	2 85	$1 20	$0 70	2 80	0 25	3 40	13 30
Total for 1897.....	0 40	1 70	3 90	1 20	0 70	3 40	0 45	4 30	16 05
By last report (1896)...	23 05	19 05	10 75	9 20	5 55	4 20	6 50	....	78 30
Total to date......	$23 45	$20 75	$14 65	$10 40	$6 25	$7 60	$6 95	$4 30	$94 35

Grand total	$3,706 45
Received for volume 9 in advance	45 00
Total receipts to date..	$3,751 45
Charged and uncollected...	23 65
Total sales of Bulletin to date...............................	$3,775 10

Exchanges.—The list of institutions to which the Society donates the Bulletin remains the same as last year, with the addition of Geographischen Gesellschaft, Berne, Switzerland. The complete list is printed, with the accessions to the library, on pages 429–436 of volume 8.

Library.—With a librarian in Cleveland in touch with the Case Library, it is hoped that the Society's library may be made better known and more useful to the Fellows. All corresponding institutions and the Fellows will be asked to send material intended for the Society direct to Cleveland. With this change, the trifling expense that the library has been to the Society will be wholly removed.

Expenses.—The following table covers the cost of administration for the last fiscal year:

EXPENDITURE OF SECRETARY'S OFFICE FOR THE FISCAL YEAR, NOVEMBER 30, 1896, TO NOVEMBER 30, 1897

Account of Administration

Postage	$37 20	
Expressage	1 86	
Printing (including stationery and records)	144 12	
Meetings (not included in printing)	3 50	
Library (freight, expressage)	9 96	
Total		$196 64

Account of Bulletin

Postage (and two telegrams)	$94 95	
Expressage and freight	53 86	
Wrapping material and labels	30 02	
Printing	17 90	
Collection of checks	3 45	
Total		$200 18
Total expenditure for year		$396 82

Respectfully submitted.

H. L. FAIRCHILD,
Secretary.

ROCHESTER, N. Y., *December 20, 1897.*

TREASURER'S REPORT

To the Council of the Geological Society of America:

The accompanying statement of receipts and disbursements for the current year (December 1, 1896–December 1, 1897) exhibits in detail the present financial condition of the Society.

The chief points of interest may be summarized as follows:

The names of five Fellows have been dropped from the roll for non-payment of dues, each being three years in arrears.

Sixteen new Fellows have been elected during the year and all except two had qualified (and they have since done so) at the date when the Treasurer's books close for the year (November 30th).

The Fellows delinquent on dues for 1896 and 1897 number 15, all of whom must be dropped from the roll early in 1898 unless their dues be paid in whole or in part prior to that time.

Thirty-four Fellows are delinquent on dues for the year 1897, of whom four have paid since the closing of the Treasurer's books.

Three Fellows (S. F. Emmons, George O. Smith, and H. W. Turner) have commuted their dues for life by paying $100 each. One of these, by preference of the Treasurer, transferred to the Society a Cosmos Club bond for $100, and the invested fund is increased to that extent—from $2,900, as per last report, to $3,000 in this.

The balance in the Treasurer's hands November 30, 1896, was	$1,274 87
And the total receipts of the present year have been	3,221 69
	$4,496 56
While the disbursements have aggregated	2,453 48
Thus leaving a balance in the treasury at the close of November 30, 1897, of	$2,043 08

The interest item of $49.84 accrued to the treasury from the policy of keeping funds not immediately needed to pay current bills on deposit with the Security Trust Company of Rochester, New York, which allows the Society 4 per cent interest on monthly balances.

The interest on the permanent invested fund amounted to $170.50, and adding the last-mentioned item of $49.84, the total received from interest is $220.34, a very respectable sum.

The detailed operations of the treasury are shown below:

RECEIPTS

Balance in the treasury November 30, 1896		$1,274 87	
Fellowship fees, 1895, 2	$20 00		
" " 1896, 19	190 00		
" " 1897, 162	1,620 00		
" " 1898, 1	10 00		
		1,840 00	
Initiation fees, 14		140 00	
Life commutation fees, 2		200 00	
Interest on investments:			
Tioga township, Kansas, bonds	$70 00		
Cosmos Club bonds	82 50		
Tunnelton, Kingwood and Fairchance Railroad bonds	18 00		
On deposit in Security Trust Company, Rochester, New York	49 84		
		220 34	
Sales of publications by the Secretary:			
Deposited with Security Trust Company, Rochester, New York		821 35	
Total amount of receipts			$4,496 56

EXPENDITURES

Expenses of Secretary's office:			
Account of administration	$196 64		
Account of Bulletin	200 18		
Allowance (to include ordinary traveling and clerical expenses)	300 00		
		$696 82	
Expenses of Editor's office:			
Allowance (to include personal and office expenses)		160 00	
Expenses of Treasurer's office:			
Printing		10 50	
Publication of Bulletin:			
Printing	$1,262 22		
Engraving	317 76		
		1,579 98	
Photograph account:			
George P. Merrill		6 18	
Total amount of disbursements			$2,453 48
Balance in the treasury November 30, 1897			$2,043 08

The invested funds of the Society are as follows:

On account of publication fund:		
April 1, 1891, one Tioga township, Kansas, bond, cost $1,140.26	$1,000 00	
January 29, 1892, eight 5 per cent Cosmos Club bonds at par	800 00	
February 26, 1892, one 5 per cent Cosmos Club bond, with accrued interest, cost $100.35	100 00	
February 3, 1893, seven 5 per cent Cosmos Club bonds at par, cost $700	700 00	
May 1, 1895, two 10-20 gold bonds of Tunnelton, Kingwood and Fairchance railroad, bearing interest from January 1, 1895, cost $204	200 00	
September 27, 1895, one bond of Tunnelton, Kingwood and Fairchance railroad, with interest from July 1, 1895, cost $100	100 00	
January 27, 1897, one 5 per cent Cosmos Club bond, No. 56, first series, cost $100	100 00	
		$3,000 00

Respectfully submitted.

I. C. White,
Treasurer.

Morgantown, West Virginia, *December 14, 1897.*

Editor's Report

To the Council of the Geological Society of America:

In submitting his annual report the Editor begs to state that the first brochure of volume 8 was completed on December 31, 1896, and the last one on April 30, 1897, the date which has come to mark the closing of the Society's publication year. Although this bulletin contains only 446 pages—thus representing the smallest issue of the Society so far as pages go—it is the most generously illustrated volume thus far published, in that it contains 51 plates, or nearly double that of any of its predecessors. For the first time the attempt was made, and with success, to employ colored illustrations. This gratifying result was obtained largely through the cooperation and generosity of the author of the brochure. It is a matter of congratulation that the Society has now reached a financial strength which permits the publication of papers in the very best possible form. Despite the profuse illustration of volume 8, a comparison of its cost with that of previous volumes will show that the total expenditure for it was but little, if any, above the average.

The publication of volume 9 was taken up in December, and all papers of the Detroit or summer meeting placed in the Editor's hands are now in type, and will make between 60 and 75 pages of printed matter.

The attention of members is called to the fact that next summer's meeting will inaugurate the tenth publication year of the Society, and the suggestion is offered that a complete index of the bulletins issued during this period would be of value to the readers. Detailed plans for the execution of this suggestion, should it meet with favor, are naturally left to the Society and the Council.

It seems desirable, both for the benefit of the Publication Committee and the members, to continue to present a general analysis of the space given the various branches of geological research in each volume as issued. As previously stated, an exact classification is not possible, but the contents of the two volumes are fairly presented in the following comparative table:

Divisions.	*Vol. 7. Pages.*	*Vol. 8. Pages.*
Terminology	1	..
Dynamic geology	3	24
Economic geology	4	14
Relation of geology to pedagogy	12	..
Stratigraphic geology	21	67
Memoirs of deceased members	28	8
Areal geology	38	34
Petrology	40	43
Physiographic geology	53	5
Official matter	56	69
Rock decomposition	74	26
Glacial geology	105	98
Paleontology	123	58
Total	558	446

The cost of each of the eight volumes thus far issued by the Society is as follows :

	Vol. 1. (pp. 593; pls. 13)	Vol. 2. (pp. 662; pls. 23)	Vol. 3. (pp. 541; pls. 10)	Vol. 4. (pp. 458; pls. 10)	Vol. 5. (pp. 665; pls. 21)	Vol. 6. (pp. 528; pls. 27)	Vol. 7. (pp. 558; pls. 24)	Vol. 8. (pp. 446; pls. 51)
Letter-press.	$1,473 77	$1,992 52	$1,535 59	$1,286 39	$1,887 21	$1,341 93	$1,463 60	$1,262 22
Illustrations..........	291 85	463 65	383 35	173 25	178 40	221 62	200 24	317 76
	$1,765 62	$2,456 17	$1,918 94	$1,459 64	$2,065 61	$1,563 55*	$1,663 84*	$1,579 98

Respectfully submitted. JOSEPH STANLEY-BROWN,
Editor.

WASHINGTON, D. C., *December 20, 1897.*

Upon motion of the Secretary, it was voted to lay the report of the Council upon the table for one day.

As the Auditing Committee, to examine the accounts of the Treasurer, the Society elected W. N. Rice and H. M. Ami.

ELECTION OF OFFICERS

The result of the balloting for officers for 1898, as canvassed by the Council, was announced by the Secretary, and officers were declared elected as follows :

President :

JOHN J. STEVENSON, New York City.

First Vice-President :

BENJ. K. EMERSON, Amherst, Mass.

Second Vice-President :

GEORGE M. DAWSON, Ottawa, Ont.

Secretary :

H. L. FAIRCHILD, Rochester, N. Y.

Treasurer :

I. C. WHITE, Morgantown, W. Va.

Editor :

J. STANLEY-BROWN, Washington, D. C.

* The actual cost to the Society was $77.50 less for volume 6, and $90.80 less for volume 7, those amounts being paid by authors for illustrations and correction charges.

Librarian:

H. P. CUSHING, Cleveland, O.

Councillors (term expires in 1900):

ROBERT BELL, Ottawa, Ont.
M. E. WADSWORTH, Houghton, Mich.
W. M. DAVIS (for unexpired term of B. K. Emerson).

ELECTION OF FELLOWS

The result of the balloting for Fellows, as canvassed by the Council, was announced, and the following persons were declared elected Fellows of the Society:

JOHN MASON CLARKE, A. B., A. M., Albany, N. Y. Assistant State Geologist and Paleontologist; Professor of Geology in Rensselaer Polytechnic Institute, Troy, N. Y.

GEORGE L. COLLIE, B. A., Ph. D., Beloit, Wis. Professor of Geology in Beloit College.

ARTHUR M. MILLER, A. B., A. M., Lexington, Ky. Professor of Geology in State College of Kentucky.

JAMES EDWARD TALMAGE, A. C., Ph. D., Salt Lake City, Utah. Deseret Professor of Geology in University of Utah.

AMENDMENTS TO CONSTITUTION

The result of the balloting on amendments to the Constitution of the Society, as canvassed by the Council, was announced. The following modifications of article IV, sections 1 and 6, had received affirmative votes from more than three-fourths of the total membership entitled to vote under the By-Laws and were therefore adopted:

To amend article IV, section 1, by including the words "an editor," so that the section shall read: "I. The officers of the Society shall consist of a President, First and Second Vice-Presidents, a Secretary, a Treasurer, an Editor, and six Councillors."

To amend article IV, section 6, by omitting the words "Society may elect an;" also all the words after the first "Council," and changing "to" to "shall," so that the section shall read: "6. The Editor shall supervise all matters connected with the publication of the transactions of the Society, under the direction of the Council."

Professor Frank D. Adams made announcement of certain details of the program and of the evening reception and the annual dinner.

The following memoirs of deceased Fellows were read:

MEMOIR OF EDWARD D. COPE

BY WILLIAM B. SCOTT

Professor Cope's attention was first attracted to science by his observation of animals, and to this, his first love, he remained true throughout his marvelously energetic and productive career. While he was a naturalist in the broadest sense of that term and felt the keenest interest in every branch of science, yet his own investigations were almost invariably connected, directly or indirectly, with the problems of life, with the structure, functions, development, and phylogenetic descent of animals, as well as with the broad metaphysical questions which underlie and condition all those problems. The pursuit of these investigations early led him to turn his attention to paleontology as affording the surest and indeed the only sure method of determining the successive modifications by which the assemblage of living beings has come to be what we see it today. The explorations of the Hayden Survey had opened a new world of extraordinary wealth and promise to the paleontologist, and into the pioneer work of examining this new world Cope threw himself with all his characteristic energy and zeal. Doubtless the greatest and most enduring monument to his fame will prove to be the gigantic work which he accomplished among the extinct vertebrates of the Far West, the biological aspects of which are the most important.

Inextricably involved in this great task were the investigations which he made in geology. These investigations were, in his own eyes, altogether subordinated to paleontological ends, and hence we find that he has comparatively little to say concerning structural or dynamical problems, but that he regarded every geological question from the strictly historical point of view. It was in stratigraphy, in determining the limits, distribution, succession, and geological date of the formations and in correlating them with their equivalents in other parts of the world, that his geological work lay. He recognized the all-important fact that the phylogenies of the various animal groups could be made out only after the true chronological order of succession of the genera composing the phyletic series had been determined.

When Cope began his studies the western region was still a comparatively new, and for the most part, geologically unexplored country, and in many instances the paleontologist was compelled perforce to turn geologist and work out the stratigraphical succession for himself. Not that Cope was by any means alone in this task, but in his own peculiar field he had to rely principally upon his own observations, which was an extremely fortunate circumstance. The greater part of Leidy's paleontological work was done with material collected by others in regions which he had never been able to visit. In those days the art of collecting fossil vertebrates was in its infancy and consisted chiefly in picking up the bones which had been weathered out of the matrix and lay loose upon the surface of the ground. Fossils from very different geological horizons were thus sometimes mingled together, and the faunal lists drawn up from such heterogeneous material led to some very erroneous inferences. Cope escaped this danger by examining the formations himself and by collecting much of his material with his own hands. This statement is not meant to imply that he gathered his enormous collections alone and unassisted, which would have been physically impossible, but that he had himself collected in almost all the formations which he describes, and that he had made himself personally familiar with the stratigraphy of nearly every one of these horizons.

Valuable as it was and still is, we see that Cope's geological work was rather of the nature of an introduction to his paleontological investigations. Hence many important geological observations are scattered through his paleontological papers, and it would require long and arduous labor to collect them all.

In a brief and hurried sketch like the present only the broader outlines of our subject can be indicated and only a few of the most salient points emphasized. To do it full justice would not only require far more time than I have been able to devote to it, but would exhaust the patience of the most long-suffering hearers. To appreciate the epoch-making character of these investigations we should remember that when Cope first undertook his labors the haziest ideas were entertained regarding the position and succession of the numerous and extensive fresh-water formations which characterize the western part of the country. It would be making an exaggerated claim to say that he had brought order out of this chaos, but it is hardly too much to say that he more than any other single individual contributed to this great result. Such was his power of insight that he was occasionally too far ahead of his contemporaries, and only of late have certain of his views received their just meed of appreciation, and in some instances we are coming back to the opinions which he first promulgated, but which were ignored or rejected.

The most convenient way of surveying Cope's work in geology will be to take it up in the order of geological chronology, though in a more detailed account it would perhaps be preferable to follow the order in which the work was done, as that would serve to display the gradual development and change in his opinions.

As Cope's principal investigations lay in the domain of vertebrate paleontology, he has comparatively little to say concerning the Paleozoic rocks, though to this statement there is one notable exception, the Permian. As early as 1852 Marcou had reported the existence of Permian rocks in Texas, and in 1858 Swallow and Meek and Hayden had found them in Kansas; but this determination was disputed, and some authorities maintained that there was no well defined Permian in the United States. The controversy remained unsettled until the appearance of Cope's remarkable series of studies upon the amphibia and reptilia of Texas, the Permian character of which he fully established, and he also determined the presence of Permian rocks in Illinois. These results were further confirmed by the researches of I. C. White and Fontaine upon the plants and of C. A. White upon the invertebrates.

In the Triassic and Jurassic and older Cretaceous, Cope's work consisted for the most part in the identification of those horizons in regions where they had previously not been known. He did not discover new formations or correct the reference of those which had been wrongly placed in the geological column. This work, though producing no startling results, was nevertheless of high importance, especially in the Cretaceous, for the successive vertebrate faunas of the Cretaceous stages were very fully investigated. Cope was the first to discover Dinosaurian remains in the Laramie stage, and the first, I believe, to advocate the reference of that horizon to the Cretaceous, a view which then ran counter to all received opinions upon the subject, but which is now well-nigh universally accepted. It is hardly necessary to emphasize the value of this determination in giving a fixed point in those obscure formations which intervene between the typical Cretaceous and Tertiary.

It was in the unravelling of the complexities of the fresh-water Tertiaries, which cover such vast areas in the west, that Cope's most splendid services to geology were rendered, and the value of these services it is difficult to exaggerate. First of all should be mentioned his discovery and identification of the Puerco, or oldest Eocene, which may fairly be called "epoch-making." Not only was a very extensive, entirely new, and highly significant fauna brought to light, but also the existence of a long time-interval between the Laramie and the Wasatch was demonstrated, showing that the supposed continuity of sedimentation connecting those horizons was illusory. This discovery necessitated an entire change in the views concerning the geological history of the western region in post-Cretaceous times. The Puerco carried the Eocene much further back than had been expected, and opened up a new world to the paleontologist.

The succeeding Wasatch formation had been discovered and named by Hayden, but it is to Cope that we owe much the greater part of our knowledge concerning its distribution, its relations, and its place in the geological column. Personally or through his collectors he thoroughly explored the Wasatch of New Mexico and Wyoming, elucidating its fauna with wonderful skill and insight, and pointing out its close correspondence to the Suessonian of France, with which his studies in that country had made him familiar.

In the Bridger formation Cope added very largely to what was known regarding the vertebrate fauna, and established the position of the Wind River beds as forming a substage at the base of the Bridger and making a transition from the older Wasatch to the Bridger proper. He also made a classical series of investigations upon the fishes of the Green River shales, and pointed out the probable equivalence in time of these beds with those of the Wind River substage. He first described the fauna of the Manti beds of Utah of approximately contemporaneous age.

The White River formation was quite thoroughly examined by Hayden, and its exceedingly rich vertebrate fauna formed the subject of Leidy's famous monographs, but Cope's studies of this remarkable horizon were of still greater importance, even though his strictly paleontological work be not taken into consideration. Leidy had determined these beds as being of Miocene age, and to this day their Miocene date is all but universally agreed upon. Cope was the first to challenge this determination and to show that the White River should rather be referred to the Oligocene. For some reason many American geologists have seemed unwilling to recognize the Oligocene as a distinct period or to make any use of the term. This is unfortunate, because it obscures the correspondences between American and European formations, and Cope was always keenly alive to the importance of determining and giving expression to these correspondences. He has found as yet few followers in referring the White River beds to the Oligocene, but in my judgment there can be no question that the reference is correct, and if so it is highly important that the change in nomenclature should be made, for to call the beds Miocene is simply misleading. An interesting discovery made by Cope was the detection of White River beds in North Dakota 200 miles north of where they had been known before, and the range of the formation was extended much farther by his studies on the fossils sent him by the Canadian Survey from the Swift Current region of the Northwest Territory. The Canadian fauna has certain resemblances to the contemporary life of Europe in addition to those which have been detected in the United States.

The Amyzon shales of Nevada and central Oregon and the Florissant beds of Colorado were also examined by Cope, who has described the important series of fishes which were obtained from these formations. While somewhat in doubt concerning the geological date of the beds, because of the lack of fossils common to them and other localities, and the absence of decisive stratigraphical evidence, he was inclined to consider them as being of late Eocene or more probably Oligocene age.

Although Cope immensely increased our knowledge of the vertebrate fauna of the John Day stage and dealt in a masterly way with the abundant fossils of that formation, yet he has little to say about its geology beyond what had already been determined by previous observers. In the Loup Fork, on the other hand, his observations were fairly revolutionary. The Loup Fork fauna was first described by Leidy, who referred it to the Pliocene. This determination was a natural one, for Leidy's material had been for the most part hastily picked from the surface of the ground and contained many specimens which had been weathered out from overlying Pleistocene deposits. This admixture of Pleistocene species gave to the fauna a very modern character, while at the same time it contained too many extinct and peculiar genera to be referable as a whole to the Pleistocene. Its determination as Pliocene was thus in a measure inevitable; but Cope was from the first suspicious of the reference, and he therefore made his collections in areas where the Loup Fork beds were at the surface and where no newer overlying strata could falsify the faunal lists. This enabled him accurately to determine the elements of which the Loup Fork fauna really consisted, and to eliminate the Pleistocene forms which had been mistakenly included in it. Having accomplished this, he came at once to the conclusion that the Loup Fork beds were not Pliocene at all, but upper Miocene. Though this determination is unquestionably right, and although it was a great reform in western stratigraphy, several American geologists have refused to adopt it, but have continued to uphold Leidy's original reference. Their example has led many European writers astray and with very unfortunate results, vitiating much careful and otherwise excellent work. Cope's observations also greatly extended the known area of the Loup Fork beds, determining their presence in New Mexico and Texas and in the valley of Mexico.

The foregoing does not exhaust Cope's important contributions to the geology of the Loup Fork, for he was the first to show that that formation is divisible into distinctly marked substages. In 1875 Grinnell and Dana discovered certain lacustrine deposits in the valley of Smith river, central Montana, which they determined as Pliocene, by that term probably meaning Loup Fork. Cope subsequently sent a collector into this region, and from the material thus gathered he made a highly important determination. He showed that these beds constituted a separate substage of the Loup Fork, and that they were older than any part of that formation which had been known up to that time. As helping to bridge over the long, unrecorded gap between the John Day and the typical Loup Fork, this discovery was of capital significance, and it eventually proved to be of great value in making correlations with the fresh-water deposits of the European upper Miocene. Cope may have been mistaken in assigning so wide a distribution as he gave to these beds in Nebraska and South Dakota, but the latest observations made in that region, while still incomplete, tend to confirm his conclusions.

What we know of the Pliocene of the interior portion of the United States is almost entirely due to the labors of Cope. From his study of the fishes he identified certain formations in Idaho and central Oregon as Pliocene and proposed the name of Idaho beds for them. These may, however, prove to be synchronous with the lacustrine deposits found in Nevada by King and by him called the Truckee beds. In Texas, Cummins discovered certain beds lying unconformably upon the Loup Fork and overlaid by the Blanco, and to these he gave the unfortunate name of "Goodnight beds," a term which has aroused the not unnatural mirth of our English cousins. The fossils collected in these beds were sent to Cope for identification, and in his skillful hands they were made to give the important result of characterizing the transition from the Loup Fork to the typical Pliocene, a result which was in complete harmony with the stratigraphical observations of Cummins. The Blanco formation of Texas is the most typical and unmistakable of the North American fresh-water Pliocenes, and almost everything that is known concerning it was made out by Cope. He examined the stratigraphy and the geographical distribution of the beds, described all the fossils which have so far been discovered in them, and determined their position in the geological column.

In the Pleistocene, Cope accomplished a great amount of work in determining the successive mammalian faunas, a knowledge of which will go far toward establishing the divisions of the North American Pleistocene upon a sound basis. This work was done not only in the Sheridan beds (the so-called Equus beds) of the west and southwest, which he studied over vast areas and in widely separated localities, but also in the caverns of the east. His attention had been very early attracted toward this fascinating subject of cave faunas, and one of the last works of his life was an elaborate study of the very extensive collections made in the Port Kennedy bone cave in Pennsylvania, under the auspices of the Academy of Natural Sciences, a cavern which had years before yielded the materials for some of his earliest investigations in this line. Nowhere else on this continent has so varied and extensive an assemblage of Pleistocene vertebrates been discovered as at Port Kennedy, and it is devoutly to be hoped that the Academy may speedily publish Cope's most valuable memoir, which must long serve as a standard of reference in this particular department. For a considerable period Cope regarded the Sheridan beds and the older cave faunas of the east (Megalonyx beds) as Pliocene; but later he revised this opinion and referred them all to the Pleistocene, a change which is unquestionably right.

In addition to this great body of investigations upon the geology of the western interior region, Cope made many important contributions to the geology and paleontology of the Atlantic coast; but in the latter case the material with which he had to deal was very fragmentary, and the results are in consequence less conclusive.

Among Cope's most valuable contributions to geology was the work which he did in correlating the various fossiliferous horizons of North America with those of Europe, a work for which his extraordinarily wide and accurate knowledge of the successive vertebrate faunas of both continents especially fitted him. Of late it has become rather the fashion to deprecate as premature all attempts at correlating American and European formations and even to deny the possibility of making such correlations in any trustworthy way. From the strictly geological point of view such a conservative attitude is natural enough; but Cope did not regard the question from a purely geological standpoint. He was, above all things, a zoologist, and his principal lifework lay in tracing the origin, phylogenies, and relationships of animals, their migrations and geographical distribution, and he clearly saw that such determinations could not be successfully undertaken unless the order of successive appearance of the various animal types in the different continents could first be established. To this end geological correlations of widely separated deposits are an indispensable necessity, and a false correlation is better as a working hypothesis than none at all, for it sets up a definite thesis in place of vague surmises. In this determination of the equivalences between the fresh-water Tertiaries of North America and those of other continents Cope was a pioneer, and while not all of his correlations have stood the test of fuller knowledge, many of them have only grown stronger with the advance of time and stand out as guide-posts in the further prosecution of the work. For example, his correlations of the Wasatch with the Suessonian of France and of the White river with the Oligocene of Ronzon have been abundantly confirmed by discoveries undreamed of when the equivalences were first suggested. The value of these determinations to the morphological paleontologist can hardly be overestimated, and every investigator owes a debt of gratitude to Cope for his labors in this department of geology.

Great as his genius undoubtedly was, Cope was not, even as an investigator, perfect and free from every fault; to use a gallicism, he had " the defects of his qualities." He was so impressed with the immensity of the work to be done, with the necessity of speed, and with the shortness of the time allotted him, and he was often so carried away by the rushing impetuosity of his thought, that he published no little hasty and ill-considered work. He frequently made blunders that a little more care and consideration would have enabled him to avoid, so eager was he to say what he had to say and then pass on to the attack of some new problem. To balance this defect, however, he had no tendency to pose as infallible, or to defend errors simply because he had himself committed them. While extremely clear as to his own opinions and the grounds upon which he held them, and while ready to give and take hard knocks in defense of his views, he was always ready, on good reason being shown, to change those views, and he allowed no weak regard for fancied consistency to hamper the freedom of his thought.

This hurried and most imperfect survey of Cope's contributions to geology may sound to some ears like a list of small and not very important services which any one who enjoyed similar opportunities might have performed; but those who are familiar with the vast and desolate regions where the work was done and who know the great difficulties which the pioneer explorer has to overcome will view the matter in a very different light and will always regard with admiration the rapidity, clear-sightedness, and skill with which the great complex of fresh-water deposits was marshaled in orderly array, their succession determined, and their equivalences with similar deposits in other parts of the world made out. To those who appreciate the difficulty of the problems involved it might well seem that Cope's contributions to geology were sufficient for one man's title to fame; but when we remember that all this geological work was done, so to speak, by the way, merely as a necessary introduction to something far larger, the prolegomena of his real life-work, admiration grows into astonishment at such powers of achievement. "Take him for all in all, we shall not look upon his like again."

In the absence of the author, the following memorial was read by J. F. Kemp:

*MEMOIR OF JOSEPH FRANCIS JAMES**

BY TIMOTHY W. STANTON

Dr Joseph Francis James, an original Fellow of this Society, was born in Cincinnati, Ohio, February 9, 1857. He died in Hingham, Massachu-

* In the preparation of this sketch Mr G. K. Gilbert has generously permitted me to use a more extended biographical notice he has prepared for publication, and also the original data furnished by Mrs James. Mr Gilbert's memoir has since been published in the American Geologist, vol. xxi, pp. 1–7.

setts, where he had established his residence only a few months before, on March 29, 1897. His love of nature in general, and especially of fossils and rocks, came to him naturally, by inheritance and association, from his father, Uriah Pierson James, a bookseller and publisher, better known to geologists as a zealous pioneer collector and student of Cincinnati fossils, many of which he described. With such a father, devoting to scientific studies all the leisure that could be taken from a business life, with the influence of the collections and membership of the Cincinnati Society of Natural History under which he grew up, with large collections of shells and fossils in his home, and with the rocks of the neighborhood filled with beautifully preserved fossils, it is not strange that Dr James became interested in paleontology, and that his principal published works relate to that subject. Paleontologists generally are to a considerable extent a product of environment. In most cases they have lived where fossils were plentiful and have begun their work as collectors. Dr James' interest, however, was not confined to a single subject. His earliest studies were in botany, and from 1877 to the end of his life he published numerous notes and articles relating to plants.

A complete bibliography of Dr James' writings would include more than two hundred titles, the list being greatly swelled by his zeal for popularizing science. Articles for newspapers and semi-scientific journals and reviews of books and scientific papers form a large proportion of the number. His geologic papers, based on his own observations, relate mainly to the Cincinnati region, including discussions of the Pleistocene geology as well as of the Ordovician rocks.

The material for most of his paleontologic work was also obtained from the Cincinnati rocks, and his papers on this subject may nearly all be found in the Journal of the Cincinnati Society of Natural History from 1884 to 1897. His Manual of the Paleontology of the Cincinnati Group, the first part of which appeared in that journal in 1891, is still in course of publication, and when complete will embrace most of Dr James' descriptive and critical paleontologic work, which was confined to Paleozoic invertebrates and to such obscure and doubtful plants as are found in the earlier Paleozoic rocks. He was very skeptical as to the organic nature of many of the obscure and "problematic organisms" that have been described as Fucoides, etcetera, and a number of papers were devoted to their discussion. His destructive criticism was useful and doubtless justified in many cases, but, as usual in such matters, it did not add much to his reputation as a paleontologist. It is a waste of labor to give much study to specimens or classes of specimens that from their nature must necessarily remain obscure and problematical.

Dr James' life was a constant and varied struggle in which his desire to keep his daily labor for maintenance as close as possible to his beloved science was ever prominent. As a young man, in 1879 he went to Los Angeles, California, to engage in a business which was soon destroyed by fire. After some months spent in a railroad construction party in southern California, Arizona, and New Mexico, he returned to Cincinnati in 1881 and was appointed custodian of the Society of Natural History. At the same time he served as Professor of Medical Botany in the Cincinnati College of Pharmacy.

In 1884 he was married to Miss Sarah C. Stubbs, a teacher of sciences in the Cincinnati High School, who, with two sons, survives him.

The position in the Society of Natural History was held until 1886, when Professor James was elected to the chair of Botany and Geology in Miami University, Oxford, Ohio. Two years later a complete change in the faculty caused his removal, but he soon received the Professorship of Natural History in the Agricultural College of Maryland, where he remained one year. He was then, 1889, appointed Assistant Paleontologist in the United States Geological Survey, where two years were spent, chiefly in office work of a routine nature.

In 1891, through an examination by the Civil Service Commission, he was appointed Assistant Vegetable Pathologist in the Department of Agriculture. While in this position his leisure hours were devoted to the study of medicine, which he had decided would be a more remunerative or, at least, a more permanent and certain means of support than pure science had proved to be, and in 1895 he graduated from the Medical School of Columbian University. After some months of hospital study and practice in New York and London he began the work of a practicing physician in Hingham, Massachusetts. From the exposure incident to that work, within a year he contracted pneumonia, which soon proved fatal.

My personal acquaintance with Professor James covered the period of his residence in Washington, beginning in 1889. I was then impressed by his eager interest in everything scientific, and I still gratefully remember his sympathetic and unselfish interest in a younger man.

THE GEOLOGICAL AND PALEONTOLOGICAL WRITINGS OF JOSEPH FRANCIS JAMES*

Catalogue of the fossils of the Cincinnati group, Cincinnati, 1881, 27 pages.

Two species of Tertiary plants: *Science*, vol. iii, April, 1884, pp. 433, 434.

Fucoids of the Cincinnati group: *Jour. Cin. Soc. Nat. Hist.*, vol. vii, 1884–1885, pp. 124–132, 151–166, with four plates.

Are there any fossil algæ?: *Am. Naturalist*, vol. xix, February, 1885, pp. 165–167.

Evidences of beaches in the Cincinnati group: *Science*, vol. v, March, 1885, pp. 231–233.

* Based on Mr Gilbert's list in American Geologist, vol. xxi, pp. 4–7.

Remarks on a supposed fossil fungus from the Coal Measures: *Jour. Cin. Soc. Nat. Hist.*, vol. viii, 1885, pp. 157-159.

Remarks on some markings on the rocks of the Cincinnati group, described under the names of Ormathicknus and Wallcottia: *Jour. Cin. Soc. Nat. Hist.*, vol. viii, 1885, pp. 160-163.

Remarks on the genera Lepidolites, Anomaloides, Ischadites, and Receptaculites, from the Cincinnati group: *Jour. Cin. Soc. Nat. Hist.*, vol. viii, 1885, pp. 163-166.

Cephalopoda of the Cincinnati group: *Jour. Cin. Soc. Nat. Hist.*, vol. viii, 1886, pp. 235-253, with one plate.

Description of a new species of Gomphoceras from the Trenton of Wisconsin: *Jour. Cin. Soc. Nat. Hist.*, vol. viii, 1886, p. 255.

Geology of Cincinnati: *Jour. Cin. Soc. Nat. Hist.*, vol. ix, 1886, pp. 20-31 [84-95].

Note on a recent synonym in the paleontology of the Cincinnati group; *Jour. Cin. Soc. Nat. Hist.*, vol. ix, 1886, p. 39 [103].

Geology and topography of Cincinnati: *Jour. Cin. Soc. Nat. Hist.*, vol. ix, 1886, pp. 136-141.

Protozoa of the Cincinnati group: *Jour. Cin. Soc. Nat. Hist.*, vol. ix, 1887, pp. 244-252.

Account of a well drilled for oil or gas, at Oxford, Ohio, May and June, 1887: *Jour. Cin. Soc. Nat. Hist.*, vol. x, 1887, pp. 70-77. Abstract in *Science*, vol. ix, June, 1887, p. 623.

Chalcedonized fossils: *Science*, vol. x, September, 1887, p. 156.

Sections of fossils: *Science*, vol. x, October, 1887, p. 180.

Microscopic sections of fossils: *Science*, vol. x, November, 1887, p. 252.

On the Monticuliporoid corals of the Cincinnati group, with a critical revision of the species. By U. P. James and Joseph F. James. *Jour. Cin. Soc. Nat. Hist.*, vol. x, 1887-1888, pp. 118-141, 158-184; vol. xi, 1888, pp. 15-47. Abstract in *Proc. Am. Assoc. Adv. Sci.*, 36th meeting, 1887, p. 223.

Sections of fossils: *Science*, vol. xi, January, 1888, p. 50.

Geological section of southwestern Ohio (abstract): *Proc. Am. Assoc. Adv. Sci.*, 36th meeting, 1887, p. 211.

Monticulipora, a coral and not a Polyzoon: *Am. Geologist*, vol. i, June, 1888, pp. 388-392.

An ancient channel of the Ohio river at Cincinnati: *Jour. Cin. Soc. Nat. Hist.*, vol. xi, 1888, pp. 96-101. Abstract in *Proc. Am. Asso. Adv. Sci.*, 37th meeting, 1888, p. 196.

The Ivorydale well in Mill Creek valley [Ohio]: *Jour. Cin. Soc. Nat. Hist.*, vol. xi, 1888, pp. 102-104.

American fossil cryptogamia: *Am. Naturalist*, vol. xxii, December, 1888, pp. 1107-1108.

Remarks upon sedimentation in the Cincinnati group: *Jour. Cin. Soc. Nat. Hist.*, vol. xii, 1889, pp. 34-36.

Curiosities of natural gas: *Pop. Sci. Monthly*, vol. xxxiv, April, 1889, pp. 821-826.

On variation with special reference to certain Paleozoic genera: *Am. Naturalist*, vol. xxiii, December, 1889, pp. 1071-1087.

On Laurentian as applied to a Quaternary terrane: *Am. Geologist*, vol. v, January, 1890, pp. 29-35.

A cave in the Clinton formation of Ohio: *Jour. Cin. Soc. Nat. Hist.*, vol. xiii, 1890, pp. 31-32.

On the Maquoketa shales and their correlation with the Cincinnati group of southwestern, Ohio: *Am. Geologist*, vol. v, June, 1890, pp. 335-356; *Postscript*, p. 394.

Section of the Makoqueta [Maquoketa] shales in Iowa [abstract]: *Proc. Am. Asso. Adv. Sci.*, 38th meeting, 1889, pp. 250, 251.

On the name "Laurentian": *Am. Geologist*, vol. vi, August, 1890, pp. 133, 134.

Fish remains of the Lower Silurian: *Scientific American*, vol. lxiv, February, 1891, p. 129.

A brief history of the Ohio river: *Pop. Sci. Monthly*, vol. xxxviii, April, 1891, pp. 739-748.

On the age of the Pleasant, Ohio, beds: *Jour. Cin. Soc. Nat. Hist.*, vol. xiv, 1891, pp. 93-104, with two plates.

Manual of the Paleontology of the Cincinnati group: *Jour. Cin. Soc. Nat. Hist.*, vol. xiv, 1891-1892, pp. 45-72, 149-163; vol. xv, 1892-1893, pp. 88-100, 144-159; vol. xvi, 1894, pp. 178-208; vol. xviii, 1895-1896, pp. 67-88, 115-140; vol. xix, 1897, pp. 99-118. [Publication still in progress.]

On problematic organisms and the preservation of algæ as fossils [abstract]: *Proc. Am. Asso. Adv. Sci.*, 40th meeting, 1891, p. 284.

The preservation of plants as fossils: *Jour. Cin. Soc. Nat. Hist.*, vol. xv, July, 1892, pp. 75-78.

Studies in problematic organisms—the genus Scolithus: *Bull. Geol. Soc. Am.*, vol. iii, 1892, pp. 32-44. No. II, the genus Fucoides: *Jour. Cin. Soc. Nat. Hist.*, vol. xvi, 1893, pp. 62-81, with one plate.

The Cincinnati ice dam: *Am. Geologist*, vol. xi, March, 1893, pp. 199-202.

Remarks on the genus *Arthrophycus* Hall: *Jour. Cin. Soc. Nat. Hist.*, vol. xvi, 1893, pp. 82-86. Abstract in *Proc. Am. Assoc. Adv. Sci.*, 42d meeting, 1893, p. 172.

Fossil fungi. Translated from the French of R. Ferry, with remarks: *Jour. Cin. Soc. Nat. Hist.*, vol. xvi, 1893, pp. 94-98.

On the value of supposed algæ as geological guides: *Am. Geologist*, vol. xiii, February, 1894, pp. 95-101.

The St Peters sandstone: *Jour. Cin. Soc. Nat. Hist.*, vol. xvii, 1894, pp. 115-135.

Remarks on Daimonelix, or "Devil's corkscrew," and allied fossils: *Am. Geologist*, vol. xv, June, 1895, pp. 337-342, with plates. Abstract in *Science*, new series, vol. i, April, 1895, p. 420.

Sponges, recent and fossil: *Am. Naturalist*, vol. xxix, June, 1895, pp. 536-545.

The first fauna of the earth: *Am. Naturalist*, vol. xxix, October-November, 1895, pp. 879-887, 979-985.

The paleontological writings of Uriah Pierson James. Compiled, annotated, and illustrated by Joseph F. James. Manuscript.

The presentation of scientific papers was declared in order under the customary rules. The first paper was entitled

SANDS AND CLAYS OF THE OTTAWA BASIN

BY R. W. ELLS

In discussion, remarks were made by F. B. Taylor, H. M. Ami, A. P. Coleman, J. B. Tyrrell, and the author. The paper is printed as pages 211-222 of this volume.

The second paper and the last one of the day's session was—

TOPOGRAPHY AND GLACIAL DEPOSITS OF THE MOHAWK VALLEY

BY ALBERT P. BRIGHAM

Remarks were made by F. B. Taylor. The paper is printed as pages 183–210 of this volume.

Session of Tuesday Evening, December 28

This session was held in the lecture hall of the Physics building, McGill University, for the presentation of the presidential address. Dr George M. Dawson introduced the President, who read his address, entitled

GEOLOGICAL PROBABILITIES AS TO PETROLEUM

BY THE PRESIDENT, EDWARD ORTON

This address is printed as pages 85–100 of this volume.

Session of Wednesday, December 29

The Society convened in the Peter Redpath Museum at 10.15 o'clock a m, President Orton in the chair.

The report of the Council was taken from the table and adopted without debate.

For the Auditing Committee, W. N. Rice reported that examination showed the report and the accounts of the Treasurer to be correct and his report had been so endorsed. The report was adopted.

Professor T. C. Chamberlin presented a resolution that President Orton be requested to convey in person to ex-President Sir William Dawson the regards of the Fellows of the Society and their regret that illness prevented his attendance upon the meeting.

Professor J. B. Porter announced the reception to be tendered the Fellows in the evening, and the Secretary asked for information as to the attendance at the dinner Thursday evening.

Professor J. F. Kemp announced that a selection from the collection of photographs was on exhibition in an adjacent room, but reserved the formal report of the Photograph Committee until the following day.

The first scientific paper was

TOPOGRAPHY AND HISTORY OF JAMESVILLE LAKE, NEW YORK

BY EDMUND C. QUEREAU

Remarks were made by W. M. Davis, H. L. Fairchild, F. B. Taylor, and A. P. Brigham. The paper is printed as pages 173–182 of this volume.

The next two papers were read by title:

LOCATION AND FORM OF A DRUMLIN AT BARRE FALLS, MASSACHUSETTS

BY WILLIAM H. NILES

DRIFT PHENOMENA OF THE PUGET SOUND BASIN

BY BAILEY WILLIS

This paper is printed as pages 111–162 of this volume.

The next paper was entitled

NOTES ON THE GEORGIAN BAY LOBE OF THE ICE-SHEET

BY FRANK B. TAYLOR

The paper was discussed by T. C. Chamberlin, H. M. Ami, Robert Bell, and Thomas Chalmers.

The next paper had been prepared by request for the occasion:

NOTES ON THE GEOLOGY OF MONTREAL AND VICINITY

BY FRANK D. ADAMS

Remarks were made by H. P. Cushing, W. M. Davis, G. M. Dawson, H. M. Ami, R. W. Ells, J. B. Tyrrell, Robert Bell, and F. B. Taylor.

In the absence of the author the following paper was, by vote of the Society, held in place, and was read by W. N. Rice:

DISCOVERY OF MARINE CRETACEOUS IN BORING AT NORFOLK, VIRGINIA

BY N. H. DARTON

[*Abstract*]

There is now in progress at Norfolk, Virginia, a boring which is intended to pass through all the coastal plain formations with the hope of obtaining a city water supply in the basal portion of the Potomac beds. As the boring was sunk at my advice, samples have been sent to me from every ten feet as the work progressed, and a large amount of valuable information has been obtained in regard to under-

ground coastal plain geology. Other deep borings have been made in southeastern Virginia, at Fort Monroe and North End Point, and although they have not yielded as definite data as could be desired, they have also added new light to the stratigraphy.

The most important feature of the Norfolk boring has been the discovery of a considerable thickness of Marine Cretaceous beds, recognized by unmistakable fossil remains. As is well known, the outcrops of Marine Cretaceous formations which are so thick in New Jersey thin to the southward and feather out in Maryland a short distance south of Washington. In eastern Virginia the Pamunkey (Eocene) formation lies directly on the eroded surface of the Potomac formation in the outcropping belt. It was of course to be expected that the Marine Cretaceous beds extended southward, underground, to come out again in the Carolina region, but definite data were most desirable in regard to their location and characteristics.

In the Norfolk well, which has now a depth of 1,760 feet (December 15, 1897), the Marine Cretaceous fossils began to appear at a depth of 715 feet, or possibly 700 feet, and they were found in great abundance down to a depth of 775 feet. Then there was a long interval, mainly of loose micaceous sands, in which no fossils were found to 1,320 feet, where there is a thin bed of reddish argillaceous sand which is supposed to have yielded a single but typical Cretaceous form. The fossils from a depth of from 715 to 775 feet were all of one species, which is the small *Exogyra*, precisely similar in general form to *E. costata*, but having a smooth surface or showing only very faint costations. They vary in length from ¼ inch to 1¼ inches. The shell from "1,320 feet" clearly is the same species, and although it is claimed by the drillers that there can be no mistake about the depth stated, I do not feel convinced as to its authenticity. However, it cannot be ignored.

Through the kindness of the Norfolk and Western Railway officials, I have been given the borings of a well sunk some years ago at Lamberts Point, which attained a depth of 616 feet. Among these borings, from depths of 568 to 616 feet, there are several Marine Cretaceous fossils, including, at 563, 603, and 610 feet, some of the *Exogyra* above mentioned, and other species, kindly determined by Mr T. W. Stanton, which are given in the following list:

Astarte octolarata, Gabb.	*Corbula* sp.
Ostrea plumosa, Morton.	*Modiola* sp.
Gryphæa vesicularis.	*Baculite* ?
Liopistha (*Cymella*) *bella*, Conrad.	

The first two are typical Ripley forms. *Liopistha* is a Snow Hill, North Carolina, form, which also occurs in the New Jersey series. In both of these wells the Chesapeake (Miocene) formation extends to within a very short distance of the Marine Cretaceous deposits. The intervening Pamunkey (Eocene) formation is apparently not over 40 feet thick.

Two years ago a well was bored at the Chamberlain hotel at Fort Monroe, and although I did not see the borings, some of them were obtained by Mr L. Woolman, of Philadelphia, and a much worn shell fragment shown to me by him was regarded as a portion of *Terebratula harlani*. The layer from which this was derived is believed to be at a depth of about 840 feet, in a bed of gravel and other coarse material, extending from 840 to 845 feet. Mr Woolman has had this shell and some other fragments examined with great care by paleontologists in Philadelphia and Washington, who agree in identifying the form as the one above named. As the boring was made by the jetting process, I think that the shell fragments may have fallen from a higher stratum before the well casing was pushed down. It seems improbable that this fossil could be found so much deeper at this point than we should be led to expect it from the depth of the older *Exogyra* in the Norfolk and Lamberts Point borings, only a few miles east and up the gentle slope of the very low dip.

It is alleged that a boring at North End Point, six miles north-northeast from Fort Monroe, was sunk to a depth of 1,172 feet to "bed rock," but I could only obtain a general list of materials penetrated. The data were not sufficiently definite to even suggest the stratigraphic position of the beds, unless possibly the Potomac formation at the bottom. When the Norfolk boring is completed I will publish a somewhat detailed account of the formations which were penetrated and make a brief review of the bearing of the new data on coastal plain stratigraphy in southeastern Virginia.

Following the reading of the above paper the Society was adjourned for lunch. At 2.30 o'clock the Society reconvened and the following paper was read by the junior author:

THE CRETACEOUS SERIES OF THE WEST COAST OF GREENLAND

BY CHARLES SCHUCHERT AND DAVID WHITE

Remarks were made by W. B. Scott and T. C. Chamberlin. The paper is printed as pages 343–368 of this volume.

In the absence of the author the following note was read by the Secretary:

NOTE ON LEPIDOPHLOIOS CLIFTONENSIS

BY SIR WILLIAM DAWSON

In the bulletin of this Society for May, 1891, appeared a paper by the author on Fossils from the Carboniferous of Newfoundland, including new species of *Lepidodendron* (*L. murrayanum*). In connection with this species I noticed what seemed a closely allied form from New Brunswick, which I had named *L. cliftonense*. Later studies of this species have shown me that it should rather be placed in the allied genus *Lepidophloios*. I have so placed it in a more recent paper on that genus in the present year. It should therefore be named *Lepidophloios cliftonensis*, but is one of the species of that genus nearest to *Lepidodendron*, and especially to my *L. murrayanum* and to *L. wortheni* of Lesquereux, as I have already stated in the paper to which this note is an addendum and erratum.

Remarks upon this note and upon the great work in paleobotany of Sir William Dawson were made by David White.

The following paper was then read:

OMPHALOPHLOIOS, A NEW LEPIDODENDROID TYPE

BY DAVID WHITE

The paper is printed as pages 329–342 of this volume.

Remarks upon the fossils were made by the Secretary.

The three following papers were read in order without discussion:

THE MASTODON IN WESTERN ONTARIO

BY HENRY M. AMI

MASTODON AND MAMMOTH REMAINS FOUND NEAR HUDSON BAY

BY ROBERT BELL

This paper is printed as pages 369–390 of this volume.

FOSSIL-LIKE FORMS IN SAULT STE MARIE SANDSTONE

BY ROBERT BELL

The next paper was

SYENITE-PORPHYRY DIKES IN THE ADIRONDACK REGION

BY H. P. CUSHING

The paper was discussed by J. F. Kemp and J. P. Iddings. It is printed as pages 239–256 of this volume.

By unanimous consent a change in the printed order of papers was made, and the next paper was

CLASTIC HURONIAN ROCKS OF WESTERN ONTARIO AND THE RELATION OF HURONIAN TO LAURENTIAN

BY A. P. COLEMAN

Remarks were made by Robert Bell, G. O. Smith, G. M. Dawson, A. E. Barlow, and the author. The paper is printed as pages 223–238 of this volume.

The following paper was then read, illustrated with lantern views:

THE HARVARD GEOGRAPHICAL MODELS

BY W. M. DAVIS

By consent, the same author exhibited another series of views under the title

GRADING OF MOUNTAIN SLOPES

BY W. M. DAVIS

Remarks upon the matter of the two papers were made by J. P. Iddings and the author.

The Society then adjourned.

No evening session was held, but the Fellows of the Society were tendered a reception by Mrs Frank D. Adams and Mrs John B. Porter in the Macdonald Mining Laboratories of McGill University.

Session of Thursday, December 30

The Society was called to order at 10.10 o'clock a m, President Orton in the chair.

The report of the Photograph Committee was read by Professor J. F. Kemp, as follows:

EIGHTH ANNUAL REPORT OF COMMITTEE ON PHOTOGRAPHS

The committee have to report the addition of 137 views, bringing the full number in the collection up to 1558. The donors, named in the order of their sendings, are:

(1) W. C. Stevenson (3); (2) Field Columbian Museum, Dr O. C. Farrington (14); and (3) the U. S. Geological Survey (120).

In addition to these, the Society has received through the influence of Mr E. V. D'Invilliers the entire series of negatives, some 300 in number, belonging to the Second Geological Survey of Pennsylvania. Prints have not yet been prepared from these, but it is hoped that funds will be available so that such can be prepared in season for the next meeting.

The acceptance on the part of the committee of this last gift brings up once more the question of the advisability of securing negatives whenever possible. It will be remembered that the chairman brought this question to the attention of the Society at the Washington meeting in 1896, and that no definite action was taken.

It may be well to state in this connection that Professor P. H. Mell, of Auburn, Alabama, reports the loss by fire of negatives from which were prepared photographs numbered 310–318, inclusive; hence prints can no longer be furnished.

The attention of members desiring prints is called to the fact that application for the same should always be made to the holder of the negatives and not to the chairman of the committee.

The committee ask a continuation of the appropriation of $15.00 for expenses during 1898, and an additional appropriation of $35.00, or such part thereof as may be needed, to be used in preparing prints from the series of negatives received from the Second Geological Survey of Pennsylvania.

Respectfully submitted. GEORGE P. MERRILL, *Chairman.*

WASHINGTON, *December*, 1897.

REGISTER OF PHOTOGRAPHS RECEIVED IN 1897

Fourteen views photographed by Dr O. C. Farrington and presented by Field Columbian Museum, Chicago, 1897

Size, 4½ by 6½ inches. Figures in parentheses are original numbers

1422 (1). Till or boulder-clay, section E, Chicago drainage canal. .

1432 (2). Drift, section 5, Chicago drainage canal. Shows sudden transition from coarse drift to fine sand; also highly inclined bedding.

1424 (3). Drift, section 5, Chicago drainage canal. 200 feet below number 2. Drift very coarse; boulders are limestone.

1425 (4). Kame, section 10, Chicago drainage canal.

1426 (5). Section of kame shown in number 4, showing drift.

1427 (6). Drift on limestone, section 7, Chicago drainage canal. Bedding of both drift and limestone horizontal. Drift channeled by streams.

1428 (7). Drift on limestone, section 6, Chicago drainage canal. The upper surface of the limestone is broken and shattered at the contact with the drift apparently by resistance to glacial movement. The resistance was also unequal, part of the limestone near the contact at the right having been entirely carried away. The direction of glacial movement was from left to right.

1429 (8). "Clay pocket," section 7, Chicago drainage canal. The limestone has undergone differential internal disintegration, causing portions of the strata to fall and become tilted. The section is 36 feet in height.

1430 (9). "Clay pocket," section 10, Chicago drainage canal. The hollow formed in the limestone by disintegration has been filled from above by drift.

1431 (10). Postglacial erosion of limestone cliff, near Lamont, Illinois.

1431 (11). Nearer view of number 10.

Views in Mexico

1433 (12). Porfirio Diaz glacier, Ixtaccihuatl, Mexico. From the old terminal moraine.

1434 (13). Weathering of quartz vein, near El Bote Mine, Zacatecas, Mexico. The surrounding rock is chlorite schist.

1435 (14). Section of lava flow, El Pedregal of Tialpam, near San Angel, valley of Mexico. The vesiculation of the lava by escaping vapors is shown and the increase through relief of pressure in the size of the vesicles toward the upper surface.

Three views photographed and presented by W. C. Stevenson

Size, 3½ by 4½ inches

1436. Cambrian limestone, Earnest Station, P. R. R., near Morriston, Pennsylvania.
1437. Potsdam sandstone exposure, Rhodes quarry, Edge Hill, Montgomery county, Pennsylvania.
1438. Potsdam sandstone, Smith's quarry, Edge Hill, Montgomery county, Pennsylvania.

Thirty-four views presented by the U. S. Geological Survey (C. D. Walcott)

Size, 4½ by 6½ inches. Figures in parentheses are original numbers

1439 (345). Summit of Conness peak, Yosemite National park, on Sierra divide, U. S. Coast and Geodetic station.
1440 (349). Granite point near trail and glacial lake on Conness Peak trail, Yosemite National park.
1441 (350). Granite showing effect of cleavage fractures in producing forms of erosion, Conness Peak trail, Yosemite National park.
1442 (363). The dome above Nevada falls, Yosemite National park.
1443 (364*b*). Domes above Nevada falls, Yosemite National park.
1444 (365). Liberty cap, above Nevada falls, Yosemite National park.
1445 (365*c*). Liberty cap, above Nevada falls, Yosemite National park.
1446 (366). Fractures in granite at base of Liberty cap, Yosemite National park.
1447 (368). Vernal falls, Yosemite National park.
1448 (374*b*). Cliffs above Mirror lake, Yosemite National park.
1449 (375*b*). North dome and cliff, Yosemite valley.
1450 (376). The arches, Yosemite valley.
1451 (405). View of pegmatite rocks on Sylvan lake 6 miles north-northeast of Custer, Black hills, South Dakota.
1452 (406). View of pegmatite rocks on Sylvan lake 6 miles north-northeast of Custer, Black hills, South Dakota.
1453 (408). View of pegmatite rocks on Sylvan lake 6 miles north-northeast of Custer, Black hills, South Dakota.
1454 (410). View from the summit of Harney peak, Black hills, South Dakota.
1455 (412). View from the summit of Harney peak, Black hills, South Dakota.
1456 (415). View of eroded pegmatite rocks below the "Needles," in trail from Sylvan lake to Harney peak, Black hills, South Dakota.
1457 (417). View of eroded pegmatite rocks below the "Needles," in trail from Sylvan lake to Harney peak, Black hills, South Dakota.
1458 (418). View of eroded pegmatite rocks below the "Needles," in trail from Sylvan lake to Harney peak, Black hills, South Dakota.
1459 (436). Big Horn mountains, Wyoming. View of eastward dipping Paleozoic rocks forming eastern summit and slope of the mountains southwest of Sheridan.

1460 (452). Big Horn mountains, Wyoming. View of cliffs on Bald mountain road, east of Little Baldy.

1461 (466). Big Horn mountains, Wyoming. Eroded granite near Bald mountain, at eastern summit, overlooking valley toward Dayton.

1462 (496). View of end of ridge, illustrating faulting and thrust beds of Cambrian limestone and quartzitic sandstone, Waucobi canyon, Inyo range, California, about 3 miles above mouth of canyon.

1463 (497). Nearer view of a portion of the strata shown by number 496.

1464 (498*a*). Western side of thrust plane seen in south wall of Devils gate, Inyo range, California.

1465 (501*c*). View near headwaters of north fork of Big Pine creek, Sierra Nevada mountains, Inyo county, California.

1466 (504). Granite peak, rising from the south side of the divide, head of north fork of Big Pine creek, Sierra Nevada mountains, Inyo county, California.

1467 (506). Broken granite peak rising from the north side of divide on north fork of Big Pine creek, Sierra Nevada mountains, Inyo county, California.

1468 (507). View of upper lake on north fork of Big Pine creek, Sierra Nevada mountains, Inyo county, California.

1469 (511). Folded limestone and intruded quartzitic sandstones, south side of Devils gate, Waucobi canyon, Inyo range, California.

1470 (515*a*). Angel terrace, near Mammoth Hot Springs hotel, Yellowstone National park, Wyoming.

1471 (516). View showing method of deposition of the siliceous deposits on slope of hot springs, summit of Angel terrace, Yellowstone National park, Wyoming.

1472 (516*c*). View showing method of deposition of the siliceous deposits on slope of hot springs, summit of Angel Terrace, Yellowstone National park, Wyoming.

Forty views presented by the U. S. Geological Survey (N. H. Darton)

Size, 6 by 8 inches. Figures in parentheses are original numbers

1473 (222). Anticlinal in Lewistown limestone, South branch of Potomac river near Hopeville, West Virginia.

1474 (245). Anticlinal and thrust fault in Tuscarora quartzite, Panther gap, Virginia. Looking south.

1475 (251). Anticlinal of Tuscarora quartzite, Panther gap, Virginia. Looking south.

1476 (254). Dakota sandstone with cross-subbedding, Bennett, Nebraska.

1477 (256). Potsdam sandstone on crystalline schists one mile north of Deadwood, South Dakota.

1478 (264). Titanotherium beds, edge of Big Bad lands of South Dakota, Corral Draw, Washington county.

1479. Columbia formation on crystalline schists near N and Twenty-fourth streets, Washington, D. C.

1480. Columbia formation, basal beds, near N and Twenty-fourth streets N. W., Washington, D. C.

1481 (293). Dakota sandstone on carboniferous limestone, west bank of Platte river below Ashland, Nebraska.

1482 (310). Jail and court-house, Cheyenne county, Nebraska. Loup Fork and Gering formations resting unconformably on Brule pink clay. Looking northwest.

1483 (311). The jail, Cheyenne county, Nebraska. Gering formation resting unconformably on Brule pink clay. Looking east.

1484 (315). "Chimney rock," Cheyenne county, Nebraska. The spire is of Gering sandstone. The slopes are of Brule pink clay, containing a bed of volcanic ash. Position of the volcanic ash indicated by horse Looking west.

1485 (327). Gering formation eroded by wind-blown sand 3 miles northeast from Freeport, Banner county, Nebraska.

1486 (339). "Smokestack," Banner county, Nebraska. From the east. The smokestack is of Loup Fork conglomerate, of which other fragments are to be seen farther back on same ridge. The base of the ridge is of Brule pink clay.

1487 (341). "Smokestack," Banner county, Nebraska. From the west. The smokestack is of Loup Fork conglomerate, a fragment of an old river channel of Loup Fork times.

1488 (342). "Twin Sisters," Banner county, Nebraska. Shows Loup Fork and Gering formation lying unconformably on Brule pink clay; also volcanic ash-bed in lower gap. Looking west.

1489 (343). Conglomeratic sandstone lens in Brule pink clay 5 miles south from Gering, Scotts Bluff county, Nebraska.

1490 (344). Loup Fork conglomerate lying on Loup Fork sands 10 miles southeast from Gering, Banner county, Nebraska. Looking northwest.

1491 (345). Loup Fork conglomerate 7 miles south-southwest from Gering, Scotts Bluff county, Nebraska. Looking southeast.

1492 (348). Scotts Bluff, Scotts Bluff county, Nebraska. From north side of North Platte river, 3 miles distant. "Dome rock" in the distance. Loup Fork and Gering formations on Brule pink clay, 3 miles northwest of Gering.

1493 (355). Bad lands in Brule pink clay on south slope of Scotts Bluff, Scotts Bluff county, Nebraska. Looking northeast.

1494 (356). Bad lands just north of Scotts Bluff, Scotts Bluff county, Nebraska. Looking north to and beyond the North Platte river. Shows remnant of plain from which Bad lands have been formed. In Brule pink clay.

1495 (363). Blowout with core 3 miles south of Harrison, Nebraska. Loup Fork formation. Daemonelix beds.

1496 (364). Daemonelix beds in Loup Fork formations near head of Little Monroe canyon, Sioux county, Nebraska. Looking northeast.

1497 (365). Typical sand hills 15 miles north from camp Clarke, Nebraska. Showing smooth leeward slopes. Looking northwest.

1498 (366). Typical sand hills 15 miles north from camp Clarke, Nebraska. Showing blowouts characteristic of windward slopes. Looking southeast.

1499 (368). "Toadstool park" 3 miles northwest from Adelia, Nebraska, Sioux county. Thin sandstone layers in clays of Big Bad Land series.

1500 (371). Titanotherium beds on Pierre shale southeast side of Indian draw. Shows bed of water-bearing gravel. Washington county, South Dakota.

1501 (374). Big Bad lands. Protoceras sandstones on Oreodon clays, head of Indian draw. Looking northwest. Washington county, Nebraska.

1502. Big Bad lands. Protoceras sandstone area. Looking southeast into head of Cottonwood draw. Washington county, South Dakota.

1503. Big Bad lands. Looking southeast into Cottonwood draw from head of Indian draw. From divide on Protoceras sandstone. Washington county, South Dakota.

1504 (378). Big Bad lands. Spur of south end of Sheep mountain. Volcanic ash beds near top. Washington county, South Dakota.

1505. Big Bad lands. South end of Sheep mountain and Devils tower. Volcanic ash bed near top. Looking northeast. Washington county, South Dakota.

1506 (380). Big Bad lands. South end of Sheep mountain from the southeast. Volcanic ash bed near top. Washington county, South Dakota.

1507 (385). "Protoceras" sandstone on Oreodon beds 2 miles east of mouth of Wounded Knee creek. Looking east. Washington county, South Dakota.

1508 (388). From top of Cedar point looking north-northeast. Big Bad lands. Washington county, South Dakota.

1509 (389). Big Bad lands. Looking west-southwest from top of Cedar point. Gravel cap in foreground and volcanic ash in middle ground to the right. Washington county, South Dakota.

1510 (397). Spring and its saline deposits from Pierre shale 10 miles northwest of Chadron, Dawes county, Nebraska.

1511 (401). Fault in Gering formation in cut of B. and M. railway one-half mile north of Rutland siding, south of Crawford, Nebraska. Looking west.

1512 (402). Bad lands 6 miles northeast of Chadron, Dawes county, Nebraska. Brule sandy clay.

Thirteen views presented by the U. S. Geological Survey (G. K. Gilbert)

Size, 6 by 8 inches. Figures in parentheses are original numbers

1513 (1). Channel opened by Erian drainage while the ice-sheet occupied the Ontario basin, between Syracuse and Jamesville, New York. The channel is traversed by the Delaware, Lackawanna and Western Railroad. Looking west.

1514 (4). Channel opened by Erian drainage while the ice-sheet occupied the Ontario basin. Two miles southwest of Jamesville, New York.

1515 (30). Channel opened by Erian drainage while the ice-sheet occupied the Ontario basin. Three miles east of Marcellus village, New York. Looking east. The upland through which the channel was eroded forms the skyline at the right.

1516 (46). The Gulf. A channel opened by Erian drainage while the ice-sheet occupied the Ontario basin. Four miles west of Marcellus village. Looking east.

1517 (89). Channel opened by Erian drainage while the ice-sheet occupied the Ontario basin. Three miles west of Palmyra, New York. Looking west. The north wall, composed of drift, forms the skyline at the right. Bowlders washed out of the drift appear in the foreground.

1518 (23). Fractured anticline of post-Glacial formation in Helderberg limestone. Split Rock, near Syracuse New York. Looking north.

1519 (24). Fractured anticline of post-Glacial formation in Helderberg limestone. Split Rock, near Syracuse, New York. Looking south.

1520 (25). Watkins Glen, New York. A post-Glacial canyon in Devonian shale.

1521 (26). Water-fall in Watkins Glen, New York. A post-Glacial canyon.

1522 (27). Grouped joints in Devonian shale, Watkins Glen, New York.

1523 (84). Drumlin 4 miles south of Newark, New York. Oblique view from the northeast.

1524 (86). Side view of drumlins 5 miles south of Newark, New York. Looking west-southwest. The direction of the ice motion was from right to left.

1525. Side view of drumlin about 2 miles southwest of Jamesville, New York. Ice motion from left to right.

Twelve views presented by the U. S. Geological Survey (J. K. Hillers)

Size, 10 by 13 inches

1526. Fire Hole falls, Yellowstone National park.

1527. Canyon of Yellowstone from the brink of lower falls, Yellowstone National park.

1528. Lower falls of Yellowstone, Yellowstone National park.

1529. The Paint Pots, Yellowstone National park.

1530. Beehive, Yellowstone National park.

1531. Lone Star geyser in eruption, Yellowstone National park.

1532. Excelsior geyser, Yellowstone National park.

1533. Fountain basin, Yellowstone National park.

1534. Upper formation of Yellowstone canyon, Yellowstone National park.

1535. Minerva terrace, Mammoth hot springs, Yellowstone National park.

1536. The Castle geyser in action, Yellowstone National park. Its well on left; Old Faithful on right beyond.

1537. Upper geyser basin, Yellowstone National park.

Eight views presented by the U. S. Geological Survey (J. Erbach)

Size, 10 by 13 inches. Figures in parentheses are original numbers

1538 (14). Outcrop of coal at Bingly slope, in the north end of the Black Heath basin. View along a recent slope. Looking north 12° west, magnetic.

1539 (45). James river between Richmond and Manchester. From South Ninth Street bridge, looking upstream. Atlantic Coast Line bridge shown.

1540 (76). Irwin Bass place, western border, south of Mosley Junction. Upper part of ravine in gneiss just west of border. Shows terraces and graded streams. Recent stream work.

1541 (77). A dry swamp hole northwest of Skinquarter, Virginia, showing mud-cracks and grass border. September 13, 1897, after a protracted drought.

1542 (109). Fragment of prismatic coke from Saunder's slope, at Gayton, between 600 and 700 foot level, at contact with decomposed vertical trap dike This is the popping coke.

1543 (113). An outcrop of the columnar coke, north of Saunder's slope, in valley of small stream. Columns dipping 36° plus toward north 70° west, magnetic. Slaty band at top. Strike of slaty band north 25° east, magnetic.

1544 (131). View of south bank of James river from Mr Parson's house, at Vinita, Virginia. James River flood-plain in foreground. Looking south.

1545 (135). James river and Cornwallis hill. Looking north 70° west, magnetic, from edge of bluff at Goat hill.

Six views presented by the U. S. Geological Survey (Whitman Cross)

Size, 7½ by 9½ inches. Figures in parentheses are original numbers

1546 (262). La Plata mountains, Colorado. Looking up Boren gulch from the southeast. Babcock and Spiller peaks in the center. The peaks mainly made up of a diorite stock cutting Mesozoic strata. An irregular diorite-porphyry body causes jagged cliffs on the left side of Boren gulch.

1547 (268). Cliffs at the head of Bedrock gulch, La Plata mountains, Colorado. Formation of cliffs is La Plata Jurassic sandstone, much indurated.

1548 (270). A ravine at the head of Bedrock gulch, La Plata mountains, Colorado. The rock here is much shattered and highly altered diorite-porphyry.

1549 (272). Mount Lewis, La Plata mountains, Colorado. View from the southeast. The peak consists of Triassic sandstones, etcetera, with numerous sheets and dikes of diorite-porphyry, and a small stock of diorite, producing much metamorphism of the strata.

1550 (274). Silver peak, La Plata mountains, Colorado. View from the northeast. The mountain is a huge irregular mass of diorite-porphyry and diorite in Mesozoic beds.

Seven views presented by the U. S. Geological Survey (J. S. Diller)

Size, 4½ by 6½ inches. Figures in parentheses are original numbers

1551 (278). The Sharkstooth, La Plata mountains, Colorado. The upper exposures are of a diorite-porphyry sheet intruded into Cretaceous shales. The lower cliffs are of a sheet in the Jurassic shales. Illustrates formation of talus slopes.

1552 (363). Sea cliff near Rose's, 1½ miles inland and about 100 feet above the present beach at Five-mile point. Rose's black sand mine is at the foot of this bluff.

1553 (364). Rose's black sand mine. The bedrock in the foreground of Eocene shales and highly tilted. Upon this rests the black sand, which is overlaid by a considerable thickness of sands and clays.

1554 (382). The cable and house of the light-house keeper at mouth of Coos bay.

1555. Hon. C. D. Walcott, Director U. S. Geological Survey; Major J. W. Powell, Director U. S. Bureau of Ethnology; Sir Archibald Geikie, Director of Geological Survey of Great Britain.

1556. Geikie excursion party, Jefferson rock, Harpers Ferry, West Virginia, May, 1897.

1557. Geikie excursion party, Jefferson rock, Harpers Ferry, West Virginia, May, 1897.

1558. Geikie excursion party, Jefferson rock, Harpers Ferry, West Virginia, May, 1897.

The report was adopted and the requested appropriations made.

Professor F. D. Adams announced that the Fellows were invited to an afternoon tea, given by Mrs Adams and Mrs Findley, during the interval between the final adjournment of the Society and the annual dinner in the evening.

The order of the printed program was changed by unanimous consent, and the two following papers were both read by Professor Adams and discussed as one:

NODULAR GRANITE FROM PINE LAKE, ONTARIO

BY FRANK D. ADAMS

CHEMICAL COMPOSITION OF THE GRANITE FROM PINE LAKE, ONTARIO

BY NEVIL N. EVANS

The papers were discussed by J. P. Iddings, Whitman Cross, and the authors. The two papers are printed, under the first title, as pages 163–172 of this volume.

The next paper was read by the senior author:

EXPERIMENTS ON THE FLOW OF ROCKS NOW BEING CONDUCTED AT MCGILL UNIVERSITY

BY FRANK D. ADAMS AND JOHN T. NICHOLSON

Remarks were made by J. F. Kemp and the President.

The two following papers were read and discussed as one:

THE GEOLOGICAL VERSUS THE PETROGRAPHICAL CLASSIFICATION OF IGNEOUS ROCKS

BY WHITMAN CROSS

THE CLASSIFICATION OF IGNEOUS ROCKS

BY JOSEPH P. IDDINGS

Remarks upon the two papers were made by J. F. Kemp and H. D. Campbell. The papers are printed in the Journal of Geology, vol. vi, pages 79–111.

FIGURE 1

FIGURE 2

SHALE EXPOSURE ON THE OHIO RIVER BLUFF OPPOSITE BEAVER, SHOWING CONCENTRIC WEATHERING

The Society then adjourned for lunch until 2.30 o'clock p m. Upon reconvening, Vice-President Emerson occupied the chair.

In the absence of the authors the two following papers were read by title:

ON THE OCCURRENCE OF CORUNDUM IN NORTH HASTINGS, ONTARIO

BY A. E. BARLOW

ESTIMATES AND CAUSES OF THE SHORTENING OF THE OUTER PART OF THE EARTH'S CRUST

BY C. R. VAN HISE

This paper by Professor Van Hise is not printed in the Bulletin, but another paper is printed in its place, entitled "Metamorphism of Rocks and Rock Flowage," which forms pages 269–328 of this volume.

In the absence of the author the following paper was read by G. O. Smith:

CONCENTRIC WEATHERING IN SEDIMENTARY ROCKS

BY THOMAS C. HOPKINS

Concentric weathering, while a common occurrence in many fine-grained, massive, igneous rocks, is rather uncommon in the sedimentary rocks, except in the form of concretions, such as clay, clay-ironstone, and flint concretions. In such cases the weathering only intensifies or emphasizes the concentric structure that already existed in the rock, due to segregation of foreign material.

Several conspicuous examples of concentric weathering in apparently homogeneous sedimentary rocks were observed by the writer in his field-work this summer, which he takes the liberty of presenting to the Society, thinking they may have as much interest for others as they had for him. The accompanying photographs will show the character of the weathered surface fairly well. Four of them are taken from exposures in the Ohio valley below Pittsburg, and one along the Conemaugh river, in Indiana county.

Figures 1 and 2, plate 27, show the appearance of a bed of argillaceous shale after an exposure of about 25 or 30 years. The exposure is the face of a rock cut on the side of the wagon road on the bluff of the Ohio river opposite Beaver, in Beaver county. The shale belongs geologically but a few feet above the Lower Kittanning coal-bed. A glance at the photograph will show the presence of a double concentricity, the larger or outer one starting from the joint-planes, rounding off the corners, giving a rounded concentric-like form to the whole mass between the joint-planes. This in no essential particulars differs from the exfoliation common in rocks, except the conspicuous action at the joints. Inside the grosser structure smaller concentric bodies are plainly visible on both sides of the joint-planes in figures 1 and 2, plate 27, These smaller concentric bodies have no perceptible difference in either color or composition from the surrounding mass in which they occur, nor do they, so far as observed, affect the lines of lamination in any way, nor are they affected by them.

Plate 28 is a photograph of the rock cut on the Pittsburg, Fort Wayne and Chicago railroad, a half mile east of Rochester, Beaver county, of a bed of shale underneath the Lower Kittanning coal-bed. This is a little fresher exposure than figures 1 and 2, plate 27—that is, the cut was made deeper, and the concentric forms started presumably from a fresh plane surface when the railway was constructed. The small concretions are prominent, but the grosser ones less pronounced.

Figure 1, plate 29, is a view of the bluff at the roadside on the east side of Block House run, at New Brighton, about 50 feet below the Lower Kittanning coal-bed, and near the same horizon as the stratum shown in plate 28. The concentric features are not quite so conspicuous as in the other views, yet plainly shown. There is lack of homogeneity in structure shown by the presence of the hard sandy layer, but it does not appear to have any direct relation to the concentric features.

Figure 2, plate 29, is a view in the recently opened clay quarry of Reese, Hammond & Co. of Bolivar. The quarry is in Indiana county, on the hill on the north side of the Conemaugh river, and the material shown in the picture is flint fire-clay. Large concentric protuberances like volcanic bombs may be observed on the face of the quarry. In some places these concretions are very abundant, and vary in size from a few inches to two feet or more in diameter. In some instances the concretions are almost entirely clay-ironstone, sometimes, near the surface, iron oxide or limonite, and frequently a mixture of the clay and iron in varying proportions. In some cases they are apparently as rich in clay as the surrounding mass in which they occur, and those in the view contain so little iron that they are used for making firebrick, which burn to a light cream color. While the occurrence of the clay ironstone nodules is evidently due to the segregation of the iron, the explanation of the clay concretions is not so clear.

The phenomenon gives rise to this question: Is the occurrence of concentric nodules due to the segregation of foreign matter, or is the segregation of foreign matter due to concentric structure? Is the segregation of material due to previous concentric structure in the homogeneous material? May not the shale concretions in above localities be due to the absence of circulating foreign material to segregate? This is put in the form of a question because the writer has not sufficient evidence to establish an affirmative answer, but sufficient to raise the question as a possible aid to co-workers. Should it be answered in the affirmative, there still remains the query, What causes concentric structure in a homogeneous sedimentary rock? Are the centers of the nodules points of first induration which spread outward in circles, or final points of induration in a hardening mass, or due to other causes subsequent to induration?

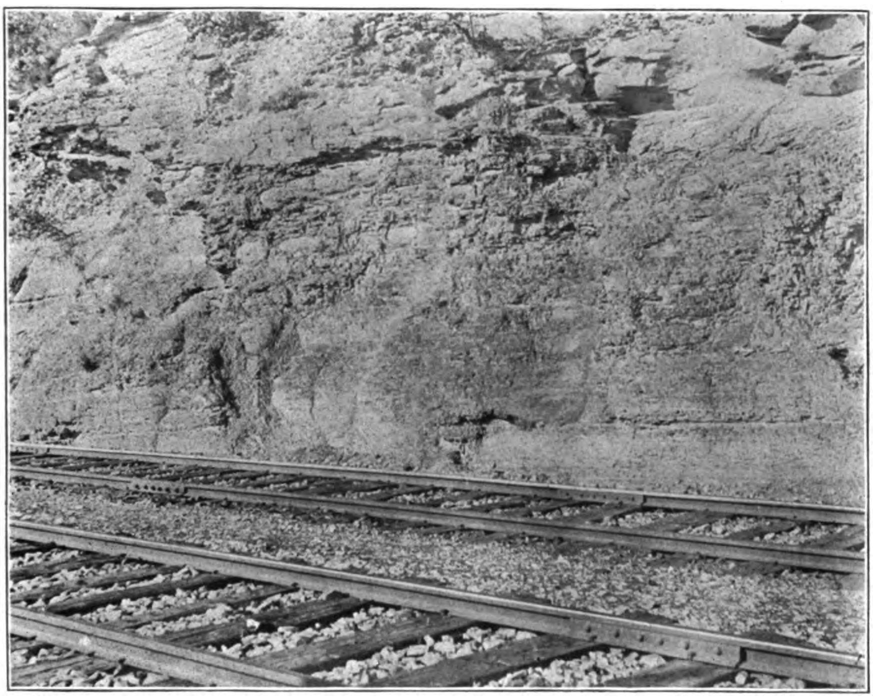
During the reading of the above paper Vice-President Emerson yielded the chair to President Orton.

In the absence of the author, the following paper was read by W. B. Scott:

NEW GEOTHERMAL DATA FROM SOUTH DAKOTA

BY N. H. DARTON

The next paper, in the absence of the author, was read by J. J. Stevenson.



ROCK CUT ON THE PITTSBURG, FORT WAYNE AND CHICAGO RAILROAD A QUARTER OF A MILE EAST OF ROCHESTER, PENNSYLVANIA, SHOWING CONCENTRIC WEATHERING IN THE SHALE

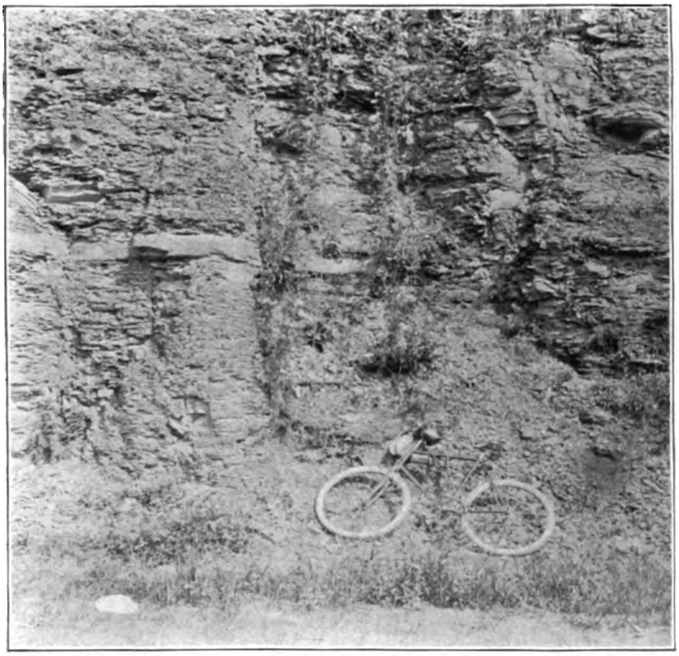


FIGURE 1

CONCENTRIC WEATHERING IN THE SHALE ON BLOCK HOUSE RUN AT NEW BRIGHTON, PENNSYLVANIA

FIGURE 2

CONCENTRIC WEATHERING IN FLINT FIRE-CLAY (THE BOLIVAR CLAY) AT BOLIVAR, PENNSYLVANIA

NOTE ON AN AREA OF COMPRESSED STRUCTURE IN WESTERN INDIANA

BY GEORGE H. ASHLEY

During the past summer, while engaged in a survey of the coal-fields of Indiana, it was the writer's privilege to find a small area in which the structure showed evidences of compression most clearly and unmistakably. The fact is of interesl in view of the general rule which holds in the Illinois basin, that all structurat irregularities are of the tension order. The abundant faults* are normal faults. Joints in the coal or rock are perpendicular and regular. Where pressure seems to have been at work it is usually found when traced down to be due to a lateral component of a vertical pressure due to load, the action taking place as a result of differential shrinkage of the coal-beds. Thus it is usual where a V-shaped channel has been cut well down into the coal and filled with sandstone to find the coal on either side of such a channel filling thickened and bearing internal evidence of compression. In such cases, however, the cause is purely local and due primarily to the difference in compressibility of the coal and sandstone acting to throw a disproportionate load on the sandstone, which, then acting as a wedge, simply squeezes out the coal from under itself or forces it down into the underlying clay, if that be soft.

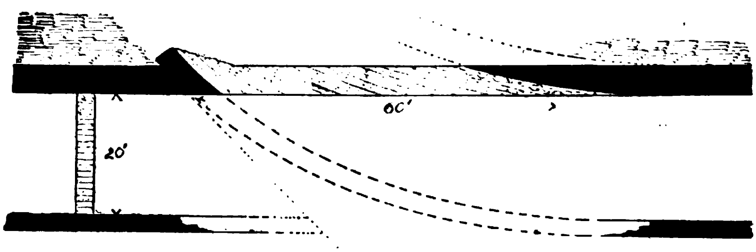


FIGURE 1.—*Reversed Fault, Columbia No. 4 Mine.*
Showing data observed in entry and small test shaft and its interpretation.

In the case to be described, however, the area affected covers several square miles and must be recognized as due to distinctly different causes. This area is in Clay county, and lies south and southwest of the little village of Asherville.

The compression is first observed in the character of the faults. As stated, over the basin in general normal faults are the rule. In this area reversed faults are the rule. Figure 1, from a sketch in Columbia No. 4 mine, may serve as a good type. In this case the overthrust is from the north, the fault line, as noted in the entry, dipped 48° to the north. It is evident here that the compressive force has acted with some power, and that no inconsiderable shortening has taken place, though how much could not be determined.

The compression is next evident in thickened and crushed coal-beds. This area

*The idea which has long prevailed that beyond the almost imperceptible westward dip of the rocks and a few indistinct folds, the strata of Indiana show no traces of structural irregularities has recently been found to have been quite erroneous. In the prosecution of the present resurvey of the coal area, structural irregularities of every kind have been found abundantly, not alone in the mines, but in surface exposures along the streams and elsewhere; faults of nearly every type, clay veins, sandstone, and coal veins, etcetera, as well as such phenomena as are mentioned in the present note.

is in the "block" coal-field, where the coal-beds are thin, ranging from 3 to 5 feet in the centers of the basins to a few inches or nothing between basins. These beds are in this area sometimes found thickened up to 10 or 12 feet—that is, from three to four times their normal thickness. Figure 2 shows the detail, in part, of a thickened bed from Columbia No. 3 mine. In this case the coal-bed, normally 3 feet 4 inches thick, has been compressed until 12 feet thick. As might be

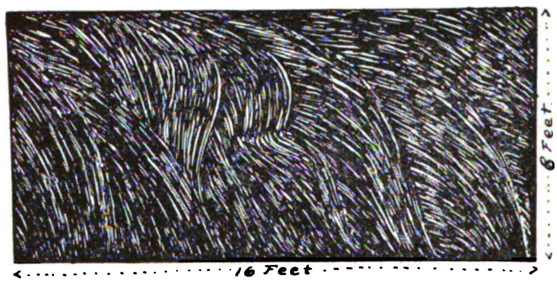


FIGURE 2.—*Sketch of detailed Structure of Part of a 3-foot 4-inch Coal Bed locally thickened to 12 feet.*

expected, the coal which is obtained at such points simply crumbles into slack when mined. At one point the strata in general have suffered until the two coal-beds worked in this area, which normally are 20 to 30 feet apart, are brought to within 6 inches of each other, the lower bed being at that point thickened up to 4½ feet and the upper bed from 4 to 6½ feet.

In a third direction the evidence comes from the peculiar joint structure common in this area. As stated above, this area lies in the "block" coal-field, where joint structure is developed in the greatest perfection. Figure 3 shows the normal joint structure of block coal. Figure 4 shows the way the same structure appears over most of this area. In some parts of the mines of this disturbed district the

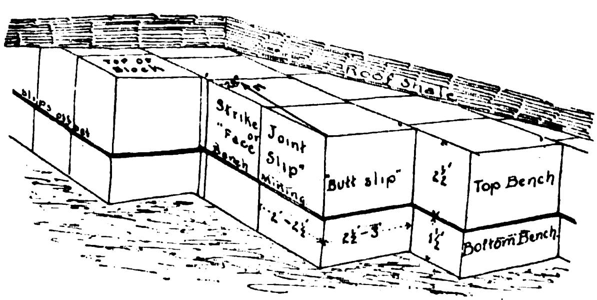


FIGURE 3.—*Diagram showing normal Structure of the upper Block Coal about Brazil, Indiana.*

normal block structure is developed, though with this slight difference, that the butt slips or joints are not quite perpendicular, but incline a little. More generally, though, the face slips disappear and the butt slips become strongly inclined to the north, dipping as low as 55 degrees, as far as measured, and where the action has been still stronger a second set of slips are developed as shown in the right of figure 4; so that when mined the coal comes out having the shape of a huge wedge.

In the second place, as indicated in figure 3, the joints are normally confined to the coal as though their cause lay in the coal itself; and even when these joints are open, as they often are, to the extent of several inches or a foot, the roof remains smooth and unbroken. But in this disturbed area all the strata suffer alike, and, as indicated in figure 4, these oblique joints penetrate the roof and floor. From their generally extending up to the surface and so forming convenient passage for water, they are commonly known locally as "water slips." Where both sets exist they render the roof very unsafe, as they cut it up into wedge-shaped blocks that tend to come down readily.

In the third place, the faces of the slips normally, though often quite even, are never polished, while in this area they are commonly slickened and highly polished—a result usually observed where compressive action has acted on rocks.

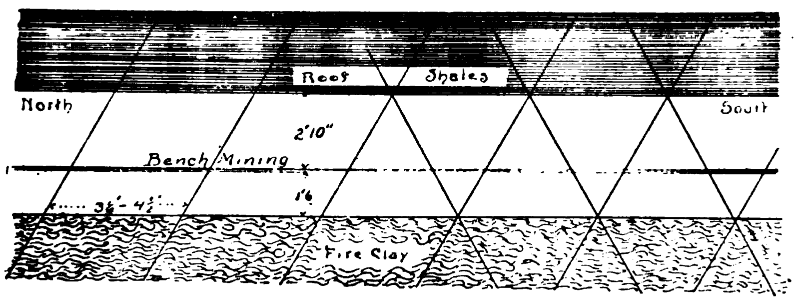


FIGURE 4.—*Joint Structure as modified by tangential Pressure.*
Section along north and south entry in Columbia No. 4 mine.

In places these inclined joints, instead of running regularly, are curved and of such shape that the coal bears a striking resemblance to cone in cone structure on a very large scale, the surface of the cones being highly polished.

Over the less disturbed portion of the block coal area the coal basins still lie so regularly that the lowest points of the old basins are still the lowest points of the coal beds and the points where the coal is the thickest, while the original rims of the basins still rise 10 to 20 feet above these basins and are the areas of thin coal. But in this district no such rule holds, the coal as often getting thick to the rise as thin, showing that the topographic irregularities of the beds here are due to subsequent earth movements, and thus bear indirect testimony in line with the evidence already given.

In conclusion, it may be stated that the evidence indicates that the pressure acted in a north-and-south line, or with the strike. I am not as yet prepared to offer any suggestions as to cause of this pressure.

In the absence of the author the following paper was presented in abstract by T. C. Chamberlin:

NIAGARA GORGE AND SAINT DAVIDS CHANNEL

BY WARREN UPHAM

This paper is printed as pages 101–110 of this volume.

The next two papers were read by title in absence of the authors:

NOTES ON THE GEOLOGY OF THE ROCKY MOUNTAINS OF MONTANA

BY WALTER H. WEED

WEATHERING OF ALNOITE IN MANHEIM, NEW YORK

BY CHARLES H. SMYTH, JR.

This paper is printed as pages 257–268 of this volume.

The last paper was

THE PRINCETON EXPEDITION TO PATAGONIA

BY W. B. SCOTT

The following resolution, presented by Professor W. B. Scott, was unanimously adopted:

"*Resolved*, That the Fellows of the Geological Society of America return their warmest thanks to the authorities of McGill University, to the resident Fellows, Professors F. D. Adams and J. B. Porter, and to Mrs Adam sand Mrs Porter and other ladies of Montreal for their kind and gracious hospitality, which has made the winter meeting of 1897 a memorable and delightful one."

President Orton stated that, as requested, he had conveyed the greetings of the Society to Sir William Dawson, who was greatly pleased at this mark of the Society's remembrance of him and had expressed his deep and constant interest in the Society.

Professors Adams and Porter invited the Fellows to make a tour of the buildings of McGill University following adjournment.

The tenth winter meeting was then declared closed.

Register of the Montreal Meeting, 1897

The following Fellows were in attendance at the meeting:

F. D. Adams.
H. M. Ami.
A. E. Barlow.
Robert Bell.
A. P. Brigham.
H. D. Campbell.
Robert Chalmers.
T. C. Chamberlin.
A. P. Coleman.
Whitman Cross.
H. P. Cushing.
W. M. Davis.
G. M. Dawson.
R. W. Ells.
B. K. Emerson.
H. L. Fairchild.
J. P. Iddings.
J. F. Kemp.
R. G. McConnell.
Edward Orton.
J. B. Porter.
E. C. Quereau.
W. N. Rice.
W. B. Scott.
G. O. Smith.
C. H. Smyth, Jr.
J. J. Stevenson.
F. B. Taylor.
J. B. Tyrrell.
David White.
I. C. White.

Total attendance, 31.

OFFICERS AND FELLOWS OF THE GEOLOGICAL SOCIETY OF AMERICA

OFFICERS FOR 1898

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J. J. Stevenson, New York, N. Y.

Vice-Presidents

B. K. Emerson, Amherst, Mass.
G. M. Dawson, Ottawa, Canada

Secretary

H. L. Fairchild, Rochester, N. Y.

Treasurer

I. C. White, Morgantown, W. Va.

Editor

J. Stanley-Brown, Washington, D. C.

Councillors

(Term expires 1898)

W. M. Davis, Cambridge, Mass.
J. M. Safford, Nashville, Tenn.

(Term expires 1899)

J. S. Diller, Washington, D. C.
W. B. Scott, Princeton, N. J.

(Term expires 1900)

Robert Bell, Ottawa, Canada
M. E. Wadsworth, Houghton, Mich.

FELLOWS, JUNE, 1898

* Indicates Original Fellow (see article III of Constitution)

FRANK DAWSON ADAMS, Ph. D., Montreal Canada; Professor of Geology in McGill University. December, 1889.

JOSÉ GUADALUPE AGUILERA, Esquela N. de Ingeneiros, City of Mexico, Mexico; Director del Instituto Geologico de Mexico. August, 1896.

TRUMAN H. ALDRICH, M. E., Birmingham, Ala. May, 1889.

HENRY M. AMI, A. M., Geological Survey Office, Ottawa, Canada; Assistant Paleontologist on Geological and Natural History Survey of Canada. December, 1889.

PHILIP ARGALL, 821 Equitable Building, Denver, Col.; Mining Engineer. August, 1896.

GEORGE HALL ASHLEY, M. E., A. M., Ph. D., 207 East Fifteenth St., Indianapolis, Ind.; Assistant Geologist, Indiana Geological Survey. August, 1896.

HARRY FOSTER BAIN, M. S., Des Moines, Iowa; Assistant Geologist, Iowa Geological Survey. December, 1895.

RUFUS MATHER BAGG, A. B., Ph. D., Baltimore, Md.; New York State Museum, Albany, N. Y, December, 1896.

S. PRENTISS BALDWIN, 1345 Euclid Ave., Cleveland, Ohio. August, 1895.

ERWIN HINCKLEY BARBOUR, A. B., Ph. D., Lincoln, Neb.; Professor of Geology, University of Nebraska, and Acting State Geologist. December, 1896.

GEORGE H. BARTON, B. S., Boston, Mass.; Instructor in Geology in Massachusetts Institute of Technology. August, 1890.

FLORENCE BASCOM, A. M., B. S., Ph. D., Bryn Mawr, Penn.; Instructor in Geology, Petrography, and Mineralogy in Bryn Mawr College. August, 1894.

WILLIAM S. BAYLEY, Ph. D., Waterville, Maine; Professor of Geology in Colby University. December, 1888.

* GEORGE F. BECKER, Ph. D., Washington, D. C.; U. S. Geological Survey.

CHARLES D. BEECHER, Ph. D., Yale University, New Haven, Conn. May, 1889.

ROBERT BELL, C. E., M. D., LL. D., Ottawa, Canada; Assistant Director of the Geological and Natural History Survey of Canada. May, 1889.

SAMUEL WALKER BEYER, B. Sc., Ph. D., Ames, Iowa; Assistant Professor in Geology, Iowa Agricultural College. December, 1896.

ALBERT S. BICKMORE, Ph. D., American Museum of Natural History, Seventy-seventh St. and Eighth Ave., N. Y. city; Curator of Anthropology in the American Museum of Natural History. December, 1889.

WILLIAM P. BLAKE, Tucson, Ariz.; Professor of Geology, Metallurgy, and Mining in University of Arizona. August, 1891.

* JOHN C. BRANNER, Ph. D., Stanford University, Cal.; Professor of Geology in Leland Stanford Jr. University.

ALBERT PERRY BRIGHAM, A. B., A. M., Hamilton, N. Y.; Professor of Geology and Natural History, Colgate University. December, 1893.

* GARLAND C. BROADHEAD, Columbia, Mo.; Professor of Geology in the University of Missouri.

* SAMUEL CALVIN, Iowa City, Iowa; Professor of Geology and Zoölogy in the State University of Iowa. State Geologist.

HENRY DONALD CAMPBELL, Ph. D., Lexington, Va.; Professor of Geology and Biology in Washington and Lee University. May, 1889.

MARIUS R. CAMPBELL, U. S. Geological Survey, Washington, D. C. August, 1892.

FRANKLIN R. CARPENTER, Ph. D., Deadwood, South Dakota; Superintendent Deadwood and Delaware Smelting Company. May, 1889.

ROBERT CHALMERS, Geological Survey Office, Ottawa, Canada; Geologist on Geological and Natural History Survey of Canada. May, 1889.

*T. C. CHAMBERLIN, LL. D., Chicago, Ill.; Head Professor of Geology, University of Chicago.

CLARENCE RAYMOND CLAGHORN, B. S., M. E., Vintondale, Pa. August, 1891.

*WILLIAM B. CLARK, Ph. D., Baltimore, Md.; Professor of Geology in Johns Hopkins University.

JOHN MASON CLARKE, A. M., Albany, N, Y.; Assistant State Geologist and Paleontologist; Professor of Geology in Rensselaer Polytechnic Institute. December, 1897.

*EDWARD W. CLAYPOLE, D. Sc., Akron, Ohio; Professor of Natural Science in Buchtel College.

JULIUS M. CLEMENTS, B. A., Ph. D., Madison, Wis.; Assistant Professor of Geology in University of Wisconsin. December, 1894.

COLLIER COBB, A. B., A. M., Chapel Hill, N. C.; Professor of Geology in University of North Carolina. December, 1894.

ARTHUR P. COLEMAN, Ph. D., Toronto, Canada; Professor of Geology, Toronto University, and Geologist of Bureau of Mines of Ontario. December, 1896.

*THEODORE B. COMSTOCK, Los Angeles, Cal.; Mining Engineer.

GEORGE L. COLLIE, Ph. D., Beloit, Wis.; Professor of Geology in Beloit College. December, 1897.

*FRANCIS W. CRAGIN, B. S., Colorado Springs, Col.; Professor of Geology and Natural History in Colorado College.

*ALBERT R. CRANDALL, A. M., Milton, Wis.

*WILLIAM O. CROSBY, B. S., Boston Society of Natural History, Boston, Mass.; Assistant Professor of Mineralogy and Lithology in Massachusetts Institute of Technology.

WHITMAN CROSS, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889

GARRY E. CULVER, A. M., 1104 Wisconsin St., Stevens Point, Wis. December, 1891.

*HENRY P. CUSHING, M. S., Adelbert College, Cleveland, Ohio; Professor of Geology, Western Reserve University.

T. NELSON DALE, Williamstown, Mass.; Geologist, U. S. Geological Survey, Instructor in Geology, Williams College. December, 1890.

*NELSON H. DARTON, United States Geological Survey, Washington, D. C.

*WILLIAM M. DAVIS, Cambridge, Mass.; Professor of Physical Geography in Harvard University.

GEORGE M. DAWSON, D. Sc., A. R. S. M., Geological Survey Office, Ottawa, Canada; Director of Geological and Natural History Survey of Canada. May, 1889.

Sir J. WILLIAM DAWSON, LL. D., Montreal, Canada. May, 1889.

DAVID T. DAY, A. B., Ph. D., U. S. Geological Survey, Washington, D. C. August, 1891.

ORVILLE A. DERBY, M. S., Sao Paulo, Brazil; Director of the Geographical and Geological Survey of the Province of Sao Paulo, Brazil. December, 1890.

*JOSEPH S. DILLER, B. S., United States Geological Survey, Washington, D. C.

Edward V. d'Invilliers, E. M., 711 Walnut St., Philadelphia, Pa. December, 1888.

Richard E. Dodge, A. M., Teachers' College, West 120th St., New York city; Professor of Geography in the Teachers' College. August, 1897.

Charles R. Dryer, M. A., M. D., Terre Haute, Ind.; Professor of Geography, Indiana State Normal School. August, 1897.

* Edwin T. Dumble, Austin, Texas, State Geologist.

Clarence E. Dutton, Major, U. S. A., Ordnance Department, San Antonio, Texas. August, 1891.

* William B. Dwight, M. A., Ph. B., Poughkeepsie, N. Y.; Professor of Natural History in Vassar College.

Charles R. Eastman, A. M., Ph. D., Cambridge, Mass.; Assistant in Paleontology in Harvard University. December, 1895.

* George H. Eldridge, A. B., United States Geological Survey, Washington, D. C.

Robert W. Ells, LL. D., Geological Survey Office, Ottawa, Canada; Geologist on Geological and Natural History Survey of Canada. December, 1888.

* Benjamin K. Emerson, Ph. D., Amherst, Mass.; Professor in Amherst College.

* Samuel F. Emmons, A. M., E. M., U. S. Geological Survey, Washington, D. C.

John Eyerman, F. Z. S., Oakhurst, Easton, Pa. August, 1891.

Harold W. Fairbanks, B. S., Berkeley, Cal.; Geologist State Mining Bureau. August, 1892.

* Herman L. Fairchild, B. S., Rochester, N. Y.; Professor of Geology in University of Rochester.

J. C. Falks, Danville, Kentucky; Professor in Centre College. December, 1888.

Oliver C. Farrington, Ph. D., Chicago, Ill.; In charge of Department of Geology, Field Columbian Museum. December, 1895.

William M. Fontaine, A. M., University of Virginia, Va.; Professor of Natural History and Geology in University of Virginia. December, 1888.

* Persifor Frazer, D. Sc., 1042 Drexel Building, Philadelphia, Pa.; Professor of Chemistry in Franklin Institute.

* Homer T. Fuller, Ph. D., Springfield, Mo.; President of Drury College.

Henry Stewart Gane, A. B., Ph. D., 425 La Salle Ave., Chicago, Ill. December, 1896.

Henry Gannett. S. B., A. Met. B., U. S. Geological Survey, Washington, D. C. December, 1891.

* Grove K. Gilbert, A. M., United States Geological Survey, Washington, D. C.

Adam Capen Gill, A. B., Ph. D., Ithaca, N. Y.; Assistant Professor of Mineralogy and Petrography in Cornell University. December, 1888.

Charles H. Gordon, M. S., Ph. D., Valley Center, Mich. August, 1893.

Ulysses Sherman Grant, Ph. D., Minneapolis, Minn.; Assistant on Geological Survey of Minnesota. December, 1890.

William Stukeley Gresley, Erie, Pa.; Mining Engineer. December, 1893.

George P. Grimsley, M. A., Ph. D., Topeka, Kan.; Professor of Geology in Washburn College. August, 1895.

Leon S. Griswold, A. B., 238 Boston St., Dorchester, Mass. August, 1892.

Frederick P. Gulliver, A. M., St. Mark's School, Southboro, Mass. August, 1895.

* William F. E. Gurley, Springfield, Ill.

Arnold Hague, Ph. B., U. S. Geological Survey, Washington, D. C. May, 1889.

* Christopher W. Hall, A. M., 803 University Ave., Minneapolis, Minn.; Professor of Geology and Mineralogy in University of Minnesota.

* James Hall, LL. D., State Hall, Albany, N. Y.; State Geologist and Director of the State Museum.

John B. Hastings, M. E., Rossland, British Columbia. May, 1889.

John B. Hatcher, Ph. B., Princeton, N. J.; Assistant in Geology, College of New Jersey. August, 1895.

* Erasmus Haworth, Ph. D., Lawrence, Kan.; Professor of Geology, University of Kansas.

C. Willard Hayes, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

*Angelo Heilprin, Academy of Natural Sciences, Philadelphia, Pa.; Professor of Paleontology in the Academy of Natural Sciences.

* Eugene W. Hilgard, Ph. D., LL. D., Berkeley, Cal.; Professor of Agriculture in University of California.

Frank A. Hill, Roanoke, Va. May, 1889.

* Robert T. Hill, B. S., U. S. Geological Survey, Washington, D. C.

Richard C. Hills, Mining Engineer, Denver, Col. August, 1894.

* Charles H. Hitchcock, Ph. D., LL. D., Hanover, N. H.; Professor of Geology in Dartmouth College.

William Herbert Hobbs, B. Sc., Ph. D., Madison, Wis.; Assistant Professor of Mineralogy in the University of Wisconsin. August, 1891.

* Levi Holbrook, A. M., P. O. Box 536, New York city.

Arthur Hollick, Ph. B., Columbia University, New York; Instructor in Geology. August, 1893.

* Joseph A. Holmes, Chapel Hill, N. C.; State Geologist and Professor of Geology in University of North Carolina.

Thomas C. Hopkins, A. M., State College, Center county, Pa. December, 1894.

* Jedediah Hotchkiss, 346 East Beverly St., Staunton, Va.

* Edmund Otis Hovey, Ph. D., American Museum of Natural History, New York city; Assistant Curator of Geology.

* Horace C. Hovey, D. D., Newburyport, Mass.

* Edwin E. Howell, A. M., 612 Seventeenth St. N. W., Washington, D. C.

Lucius L. Hubbard, A. B., LL. D., Ph. D., Houghton, Mich.; State Geologist of Michigan. December, 1894.

* Alpheus Hyatt, B. S., Boston Society of Natural History, Boston, Mass.; Curator of Boston Society of Natural History.

Joseph P. Iddings, Ph. B., Professor of Petrographic Geology, University of Chicago, Chicago, Ill. May, 1889.

Elfric D. Ingall, Geological Survey Office, Ottawa, Canada; in charge of Mineral Statistics and Mines. August, 1894.

A. Wendell Jackson, Ph. B., 407 St. Nicholas Ave., New York city. December, 1888.

Robert T. Jackson, S. B., S. D., 33 Gloucester St., Boston, Mass.; Instructor in Paleontology in Harvard University. August, 1894.

Thomas M. Jackson, C. E., S. D., Clarksburg, W. Va. May, 1889.

* Willard D. Johnson, United States Geological Survey, Washington, D. C.

Alexis A. Julien, Ph. D., Columbia College, New York city; Instructor in Columbia College. May, 1889.

Arthur Keith, A. M., U. S. Geological Survey, Washington, D. C. May, 1889.

* James F. Kemp, A. B., E. M., Columbia University, New York city; Professor of Geology.

Charles Rollin Keyes, A. M., Ph. D., 944 Fifth St., Des Moines, Iowa. August, 1890.

Wilbur C. Knight, B. S., A. M., Laramie, Wyo.; Professor of Mining and Geology in the University of Wyoming. August, 1897.

Frank H. Knowlton, M. S., Washington, D. C.; Assistant Paleontologist U. S. Geological Survey. May, 1889.

Henry B. Kümmel, A. M., Ph. D., Lewis Institute, Chicago, Ill.; Assistant Professor of Physiography. December, 1895.

*George F. Kunz, care of Tiffany & Co., 15 Union Square, New York city.

Ralph D. Lacoe, Pittston, Pa. December, 1889.

George Edgar Ladd, A. M., Ph. D., Rolla, Mo. Director, School of Mines. August, 1891.

J. C. K. Laflamme, M. A., D. D., Quebec, Canada; Professor of Mineralogy and Geology in University Laval, Quebec. August, 1890.

Lawrence M. Lambe, Ottawa, Canada; Artist and Assistant in Paleontology, Geological Survey of Canada. August, 1890.

Alfred C. Lane, Ph. D., Houghton, Mich.; Assistant State Geologist. December, 1889.

Daniel W. Langton, Ph. D., 39 East Tenth St., New York city; Mining Engineer. December, 1889.

Andrew C. Lawson, Ph. D., Berkeley, Cal.; Assistant Professor of Geology in the University of California. May, 1889.

*Joseph Le Conte, M. D., LL. D., Berkeley, Cal.; Professor of Geology in the University of California.

*J. Peter Lesley, LL. D., 1008 Clinton St., Philadelphia, Pa.; State Geologist.

Frank Leverett, B. S., Denmark, Iowa; Assistant U. S. Geological Survey. August, 1890.

Waldemar Lindgren, U. S. Geologieal Survey, Washington, D. C. August, 1890.

Robert H. Loughridge, Ph. D., Berkeley, Cal.; Assistant Professor of Agricultural Chemistry in University of California. May, 1889.

Albert P. Low, B. S., Geological Survey Office, Ottawa, Canada; Geologist on Canadian Geological Survey. August, 1892.

Thomas H. Macbride, Iowa City, Iowa; Professor of Botany in the State University of Iowa. May, 1889.

Henry McCalley, A. M., C. E., University, Tuscaloosa county, Ala.; Assistant on Geological Survey of Alabama. May, 1889.

Richard G. McConnell, A. B., Geological Survey Office, Ottawa, Canada; Geologist on Geological and Natural History Survey of Canada. May, 1889.

James Rieman Macfarlane, A. B., 100 Diamond St., Pittsburg, Pa. August, 1891.

*W J McGee, Washington, D. C.; Bureau of North American Ethnology.

William McInnes, A. B., Geological Survey Office, Ottawa, Canada; Geologist, Geological and Natural History Survey of Canada. May, 1889.

Peter McKellar, Fort William, Ontario, Canada. August, 1890.

Cyrus F. Marbut, A. M., State University, Columbia, Mo.; Instructor in Geology and Assistant on Missouri Geological Survey. August, 1897.

Oliver Marcy, LL. D., Evanston, Cook Co., Ill.; Professor of Natural History in Northwestern University. May, 1889.

Othniel C. Marsh, Ph. D., LL. D., New Haven, Conn.; Professor of Paleontology in Yale University. May, 1889.

Vernon F. Marsters, A. B., 1716 Cambridge St., Cambridge, Mass. August, 1892.

EDWARD B. MATHEWS, Ph. D., Baltimore, Md.; Instructor in Petrography in Johns Hopkins University. August, 1895.

P. H. MELL, M. E., Ph. D., Auburn, Ala.; Professor of Geology and Natural History in the State Polytechnic Institute. December, 1888.

JOHN C. MERRIAM, Ph. D., Berkeley, Cal.; Instructor in Paleontology in University of California. August, 1895.

* FREDERICK J. H. MERRILL, Ph. D., State Museum, Albany, N. Y.; Assistant State Geologist and Assistant Director of State Museum.

GEORGE P. MERRILL, M. S., U. S. National Museum, Washington, D. C.; Curator of Department of Lithology and Physical Geology. December, 1888.

ARTHUR M. MILLER, A. M., Lexington, Ky.; Professor of Geology, State University of Kentucky. December, 1897.

JAMES E. MILLS, B. S., Quincy, Plumas Co., Cal. December, 1888.

THOMAS F. MOSES, M. D., Worcester Lane, Waltham, Mass. May, 1889.

* FRANK L. NASON, A. B., West Haven, Conn.; Assistant on Geological Survey of New Jersey.

* PETER NEFF, A. M., 361 Russell Ave., Cleveland, Ohio; Librarian, Western Reserve Historical Society.

FREDERICK H. NEWELL, B. S., U. S. Geological Survey, Washington, D. C. May, 1889.

WILLIAM H. NILES, Ph. B., M. A., Cambridge, Mass. August, 1891.

WILLIAM H. NORTON, M. A., Mt. Vernon, Iowa; Professor of Geology in Cornell College. December, 1895.

CHARLES J. NORWOOD, Frankfort, Ky.; State Mine Inspector of Kentucky, August, 1894.

EZEQUIEL ORDONEZ, Esquela N. de Ingeneiros, City of Mexico, Mexico; Geologist del Instituto Geologico de Mexico. August, 1896.

* EDWARD ORTON, Ph. D., LL. D., Columbus, Ohio; State Geologist and Professor of Geology in the State University.

* AMOS O. OSBORN, Waterville, Oneida Co., N. Y.

HENRY F. OSBORN, Sc. D., Columbia University, New York city; Professor of Zoology, Columbia University. August, 1897.

CHARLES PALACHE, B. S., University Museum, Cambridge, Mass.; Instructor in Mineralogy, Harvard University. August, 1894.

* HORACE B. PATTON, Ph. D., Golden, Col.; Professor of Geology and Mineralogy in Colorado School of Mines.

RICHARD A. F. PENROSE, JR., Ph. D., 1331 Spruce St., Philadelphia, Pa. May, 1889.

JOSEPH H. PERRY, 176 Highland St., Worcester, Mass. December, 1888.

* WILLIAM H. PETTEE, A. M., Ann Arbor, Mich.; Professor of Mineralogy, Economical Geology and Mining Engineering in Michigan University.

LOUIS V. PIRSSON, Ph. D., New Haven, Conn.; Assistant Professor of Inorganic Geology, Sheffield Scientific School. August, 1894.

* FRANKLIN PLATT, 1617 Chestnut St., Philadelphia, Pa.

* JULIUS POHLMAN, M. D., University of Buffalo, Buffalo, N. Y.

JOHN BONSALL PORTER, E. M., Ph. D., Montreal, Canada; Professor of Mining, McGill University. December, 1896.

* JOHN W. POWELL, Bureau of Ethnology, Washington, D. C.

* CHARLES S. PROSSER, M. S., Schenectady, N. Y.; Professor of Geology in Union University.

* Raphael Pumpelly, U. S. Geological Survey, Dublin, N. H.

Edmund C. Quereau, Ph. D., Syracuse, N. Y.; Professor of Geology, Syracuse University. August, 1897.

Frederick Leslie Ransome, Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1895.

Harry Fielding Reid, Ph. D., Johns Hopkins University, Baltimore, Md. December, 1892.

William North Rice, A. M., Ph. D., LL. D., Middletown, Conn.; Professor of Geology in Wesleyan University. August, 1890.

Heinrich Ries, A. M., Ph. D., Columbia University, New York city; Assistant in Mineralogy. December, 1893.

Charles W. Rolfe, M. S., 601 John St., Champaign, Ill.; Professor of Geology in University of Illinois. May, 1889.

* Israel C. Russell, LL. D., Ann Arbor, Mich.; Professor of Geology in University of Michigan.

* James M. Safford, M. D., LL. D., Nashville, Tenn.; State Geologist; Professor in Vanderbilt University.

Orestes H. St. John, Raton, N. Mex. May, 1889.

* Rollin D. Salisbury, A. M., Chicago, Ill.; Professor of General and Geographic Geology in University of Chicago.

Frederick W. Sardeson, L. B., M. S., Ph. D., Instructor in Paleontology, University of Minnesota, Minneapolis, Minn. December, 1892.

* Charles Schaeffer, M. D., 1309 Arch St., Philadelphia, Pa.

Charles Schuchert, Washington, D. C.; Assistant Curator in Paleontology, U. S. National Museum. August, 1895.

William B. Scott, M. A., Ph. D., 56 Bayard Ave., Princeton, N. J.; Blair Professor of Geology in College of New Jersey. August, 1892.

Henry M. Seely, M. D., Middlebury, Vt.; Professor of Geology in Middlebury College. May, 1889.

* Nathaniel S. Shaler, LL. D., Cambridge, Mass.; Professor of Geology in Harvard University.

Will H. Sherzer, M. S., Ypsilanti, Mich.; Professor in State Normal School. December, 1890.

* Frederick W. Simonds, Ph. D., Austin, Texas; Professor of Geology in University of Texas.

* Eugene A. Smith, Ph. D., University, Tuscaloosa Co., Ala.; State Geologist and Professor of Chemisty and Geology in University of Alabama.

George Otis Smith, Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1897.

* John C. Smock, Ph. D., Trenton, N. J.; State Geologist.

Charles H. Smyth, Jr., Ph. D., Clinton, N. Y.; Professor of Geology in Hamilton College. August, 1892.

Henry L. Smyth, A. B., Cambridge, Mass.; Instructor in Mining Geology in Harvard University. August, 1894.

Arthur Coe Spencer, B. S., Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1896.

* J. W. Spencer, A. M., Ph. D., 152 Bloor St. East, Toronto, Canada.

Josiah E. Spurr, A. B., A. M., U. S. Geological Survey, Washington, D. C. December, 1894.

Joseph Stanley-Brown, 1318 Massachusetts Ave., Washington, D. C. August, 1892.

TIMOTHY WILLIAM STANTON, B. S., U. S. National Museum, Washington, D. C.; Assistant Paleontologist, U. S. Geological Survey. August, 1891.

* JOHN J. STEVENSON, Ph. D., LL. D., New York University; Professor of Geology in the New York University.

JOSEPH A. TAFF, B. S., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1895.

JAMES E. TALMAGE, Ph. D., Salt Lake City, Utah; Professor of Geology in University of Utah. December, 1897.

RALPH S. TARR, Cornell University, Ithaca, N. Y.; Professor of Dynamic Geology and Physical Geography. August, 1890.

FRANK B. TAYLOR, Fort Wayne, Ind. December, 1895.

* ASA SCOTT TIFFANY, 901 West Fifth St., Davenport, Iowa.

WILLIAM G. TIGHT, M. S., Granville, Ohio; Professor of Geology and Biology, Denison University. August, 1897.

* JAMES E. TODD, A. M., Vermillion, S. Dak.; Professor of Geology and Mineralogy in University of South Dakota.

* HENRY W. TURNER, B. S., U. S. Geological Survey, Washington, D. C.

JOSEPH B. TYRRELL, M. A., B. Sc., Geological Survey Office, Ottawa, Canada; Geologist on the Canadian Geological Survey. May, 1889.

JOHAN A. UDDEN, A. M., Rock Island, Ill.; Professor of Geology and Natural History in Augustana College. August, 1897.

* WARREN UPHAM, A. M., Librarian Minnesota Historical Society, St. Paul, Minn.

* CHARLES R. VAN HISE, M. S., Madison, Wis; Professor of Mineralogy and Petrography in Wisconsin University; Geologist, U. S. Geological Survey.

THOMAS WAYLAND VAUGHAN, B. S., A. B., A. M., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1896.

* ANTHONY W. VOGDES, Fort Wadsworth, Staten Island, N. Y.; Captain Fifth Artillery, U. S. Army.

* MARSHMAN E. WADSWORTH, Ph. D., Houghton, Mich.; State Geologist; President of Michigan Mining School.

* CHARLES D. WALCOTT, U. S. National Museum, Washington, D. C.; Director U. S. Geological Survey.

HENRY STEPHENS WASHINGTON, B. A., M. A., Ph. D., Locust, Monmouth Co., N. J. August, 1896.

WALTER H. WEED, M. E., U. S. Geological Survey, Washington, D. C. May, 1889.

LEWIS G. WESTGATE, Ph. D., 805 Sherman Ave., Evanston, Ill. August, 1894.

THOMAS C. WESTON, Ottawa, Canada. August, 1893.

DAVID WHITE, U. S. National Museum, Washington, D. C.; Assistant Paleontologist, U. S. Geological Survey, Washington, D. C. May, 1889.

* ISRAEL C. WHITE, Ph. D., Morgantown, W. Va.

* CHARLES A. WHITE, M. D., U. S. National Museum, Washington, D. C.; Paleontologist, U. S. Geological Survey.

* ROBERT P. WHITFIELD, Ph. D., American Museum of Natural History, Seventy-seventh St. and Eighth Ave., New York city; Curator of Geology and Paleontology.

* EDWARD H. WILLIAMS, JR., A. C., E. M., 117 Church St., Bethlehem, Pa.; Professor of Mining Engineering and Geology in Lehigh University.

* HENRY S. WILLIAMS, Ph. D., New Haven, Conn.; Professor of Geology and Paleontology in Yale University.

BAILEY WILLIS, U. S. Geological Survey, Washington, D. C. December, 1889.

* Horace Vaughn Winchell, 1306 S. E. Seventh St., Minneapolis, Minn; Assistant on Geological Survey of Minnesota.

* Newton H. Winchell, A. M., Minneapolis, Minn.; State Geologist; Professor in University of Minnesota.

* Arthur Winslow, B. S., care of Missouri, Kansas and Texas Trust Company, Kansas City, Mo.

John E. Wolff, Ph. D., Harvard University, Cambridge, Mass.; Professor of Petrography and Mineralogy in Harvard University and Curator of the Mineralogical Museum. December, 1889.

Robert Simpson Woodward, C. E., Columbia College, New York city; Professor of Mechanics in Columbia College. May, 1889.

Jay B. Woodworth, B. S., Cambridge, Mass.; Instructor in Harvard University. December, 1895.

Albert A. Wright, A. B., Ph. B., Oberlin, Ohio: Professor of Geology in Oberlin College. August, 1893.

* G. Frederick Wright, D. D., Oberlin, Ohio; Professor in Oberlin Theological Seminary.

William S. Yeates, A. B., A. M., Atlanta, Ga.; State Geologist of Georgia. August, 1894.

FELLOWS DECEASED

* Indicates Original Fellow (see article III of Constitution)

* Charles A. Ashburner, M. S., C. E. Died December 24, 1889.
Amos Bowman. Died June 18, 1894.
* J. H. Chapin, Ph. D. Died March 14, 1892.
George H. Cook, Ph. D., LL. D. Died September 22, 1889.
* Edward D. Cope, Ph. D. Died April 12, 1897.
Antonio del Castillo. Died October 28, 1895.
* James D. Dana, LL. D. Died April 14, 1895.
* Albert E. Foote. Died October 10, 1895.
N. J. Giroux, C. E. Died November 30, 1896.
* Robert Hay. Died December 14, 1895.
David Honeyman, D. C. L. Died October 17, 1889.
Thomas Sterry Hunt, D. Sc., LL. D. Died February 12, 1892.
* Joseph F. James, M. S. Died March 29, 1897.
* Henry B. Nason, M. D., Ph. D., LL. D. Died January 17, 1895.
* John S. Newberry, M. D., LL. D. Died December 7, 1892.
* Richard Owen, LL. D. Died March 24, 1890.
Charles Wachsmuth. Died February 7, 1896.
* George H. Williams, Ph. D. Died July 12, 1894.
* J. Francis Williams, Ph. D. Died November 9, 1891.
* Alexander Winchell, LL. D. Died February 19, 1891.

Summary

Original Fellows	84
Elected Fellows	154
Membership	238
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ACCESSIONS TO LIBRARY FROM MARCH, 1897, TO MARCH, 1898

BY H. P. CUSHING, *Librarian*

Contents

(*A*) FROM SOCIETIES AND INSTITUTIONS RECEIVING THE BULLETIN AS DONATION ("EXCHANGES") *

(*a*) *AMERICA*

NEW YORK STATE MUSEUM, ALBANY

1263–1265. Annual Report, no. 48, 1894, 3 vols.
1266. " " no. 49, 1895, part i.

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BY

H. L. FAIRCHILD, SECRETARY

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ROCHESTER
PUBLISHED BY THE SOCIETY
DECEMBER, 1898